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BARE HULL RESISTANCE AND FLOW OBSERVATION EXPERIMENTS FOR CABLE--ETC(U)
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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

BARE HULL RESISTANCE AND FLOW OBSERVATION EXPERIMENTS FOR CABLE REPAIR SHIP (T-ARC) DTNSRDC MODEL 5364

BY

HUGH Y. H. YEH

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

SHIP PERFORMANCE DEPARTMENT REPORT

SEPTEMBER 1978

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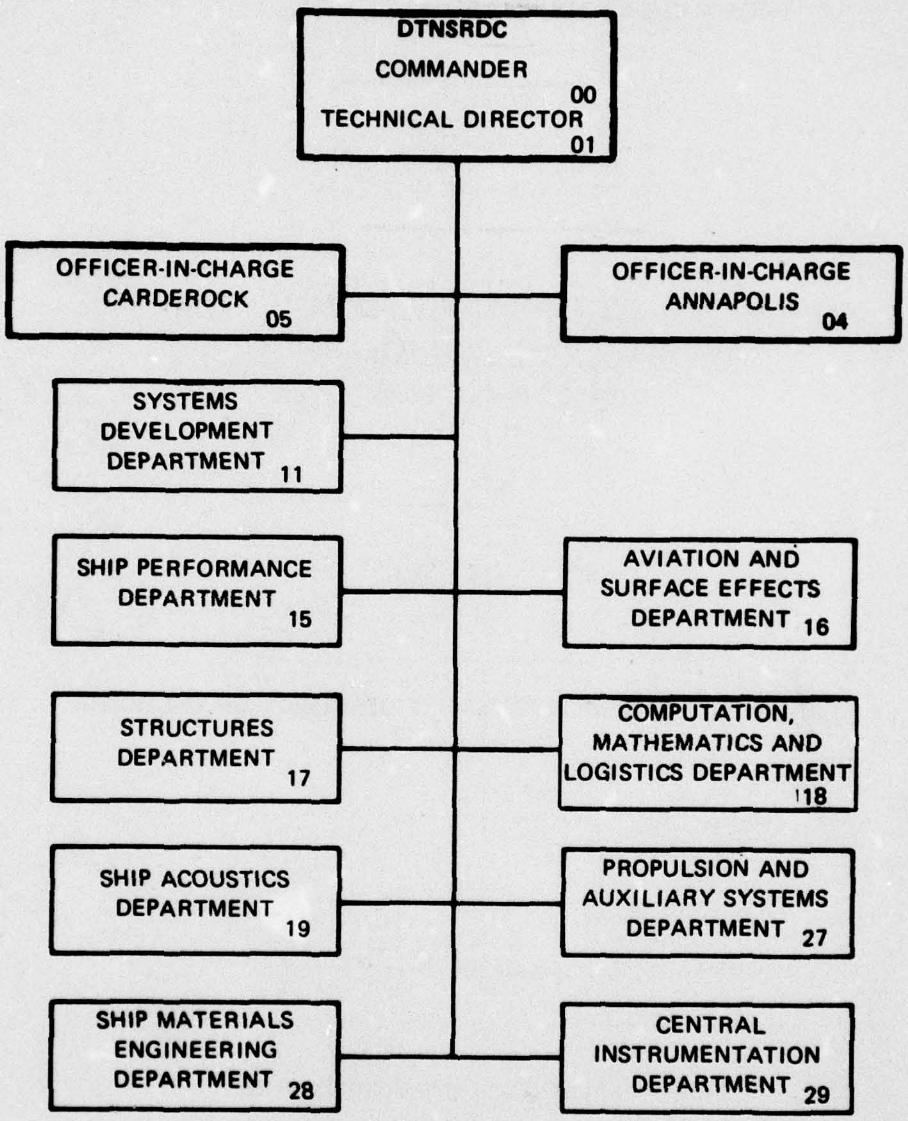

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This report presents the results of the resistance experiments of a Cable Repair Ship (T-ARC). Photographs of the flow around the underwater body as observed in the Circulating Water Channel (CWC) are also included.

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NOTATION

AX	Area, maximum transverse section
BX	Beam or breadth, moulded of ship at AX
CA	Correlation allowance
CB	Block coefficient
CP	Longitudinal prismatic coefficient
CPA	Prismatic coefficient, afterbody
CPE	Prismatic coefficient, entrance
CPF	Prismatic coefficient, forebody
CPR	Prismatic coefficient, run
CS	Wetted surface coefficient
CVP	Prismatic coefficient, vertical
CVPA	Prismatic coefficient, vertical afterbody
CVPF	Prismatic coefficient, vertical forebody
CVOL	Volumetric coefficient
CWP	Designed load waterline coefficient
CWA	Designed load waterline coefficient afterbody
CWF	Designed load waterline coefficient forebody
CWS	Taylor's wetted surface coefficient
CX	Maximum transverse section coefficient
D-L, Δ_B	Displacement length ratio
EHP_T	Total effective horsepower
EHP_F	Frictional horsepower
FTE	Taylor sectional area coefficient for bulbous bow

NOTATION (Continued)

L	Length of a ship
LE	Length of entrance
LOL	Length, overall
LP	Length of parallel middlebody
LPP	Length between perpendiculars
LR	Length of run
LWL	Length of waterline in general
S	Wetted surface
TTE	Taylor tangent to the area curve
TX	Draught, moulded of ship
XFB	Longitudinal centre of buoyancy from forward perpendicular

ABSTRACT

This report presents the results of the resistance experiments of a Cable Repair Ship (T-ARC). Photographs of the flow around the underwater body as observed in the Circulating Water Channel (CWC) are also included.

ADMINISTRATIVE INFORMATION

This work was performed at David W. Taylor Naval Ship R&D Center (DTNSRDC), Bethesda, Maryland 20084. This project was funded under Naval Ship Engineering Center (NAVSEC) Project Order 8382221, Ship Performance Department Work Unit Number 1524-637 and 1524-656.

INTRODUCTION

The Naval Ship Engineering Center (NAVSEC) requested that model tests be conducted at the David W. Taylor Naval Ship R&D Center (DTNSRDC) to evaluate the performance characteristics of a hull design representing the New Cable Repair Ship (T-ARC). This model was built in accordance with the NAVSEC Lines and Body Plan No. 53611-86, dated 15 November 1977, and designated as DTNSRDC Model 5364.

The model was constructed with properly designed openings to accommodate two bow side thrusters, two stern side thrusters and two bottom thrusters at the bow. The purpose of this model test program is to evaluate the effect of these thruster openings on the resistance characteristics and to observe the flow pattern over these openings.

EXPERIMENTS

MODEL

DTNSRDC Model 5364 representing the new T-ARC, in accordance with the NAVSEC Lines and Body Plan 53711-86, dated 15 November 1977, was built of wood with a model-ship linear ratio of 23.5368, complete with bow and stern towing sheaves, thruster openings and removable gratings for the thruster openings.

Abbreviated bare hull lines of Model 5364 are given in Figure 1. Hull form coefficients for T-ARC and Model 5364 are given in Tables 1 and 2.

Side thrusters are numbered from bow to stern (from No. 1 to No. 4), and the bottom thrusters are numbered in pairs, also from bow to stern as No. 5 and No. 6.

RESISTANCE EXPERIMENTS

Model resistance experiments were conducted in the Deep Water Basin (Carriage 1), with the model ballasted to a corresponding ship displacement of 14,530 tonnes (14,300 tons, salt water) at even keel, over a full scale ship speed range of 0 to 20 knots. Effective horsepower predictions for T-ARC based on these experiments are for the ship operated in the North Atlantic at a sea water temperature of 15 ^{o}C. The correlation allowance coefficient (C_A) of 0.0005 was used in conjunction with ITTC Friction Line. The wave Profile of T-ARC at 15 knots is shown in Figure 2. Resistance predictions are given in Figure 3 to 14 and also in Tables 3 to 14. (The corresponding figures with English units are given in the Appendix, with subscript a.). To evaluate the merit of the T-ARC

hull form from the resistance point of view, the resistance data of T-ARC have been compared with those of the corresponding hull forms, one from Taylor Standard Series and the other from the Historical Model Data. Figure 15 gives these comparative results.

Changes of level for T-ARC at various speeds as obtained during the experiments did not vary from test to test for all the experiments conducted.

Figure 16 through 21 show the model and thruster opening as built.

FLOW OBSERVATION EXPERIMENTS

Flow around the thrusters, except the bottom thrusters which were plugged, and around the stern appendages was observed in the DTNSRDC CWC. The model was ballasted to the same condition as in the resistance experiments, and was fitted with all appendages and DTNSRDC Propellers 4484 and 4485. Flow observations were aided by both dye and wool tufts some of which are attached to the hull surface and others away from the hull (0.8m full scale). Three yaw angles were investigated (0, 5, 10 degrees) both port and starboard. Photographs of these experiments are given in Figures 22 through 43.

DISCUSSION

RESISTANCE

The bare hull resistance characteristics of the T-ARC Model 5364 are compared to those from the corresponding Taylor hull in Figure 15. T-ARC has lower resistance all through the speed range. But, when the comparison was made to the one of the models in the historical model

data bank which has similar hull dimensions (indicated as "stock model" in Figure 15), the T-ARC has higher resistance above 14 knots. However, in comparing the "stock model" to its corresponding Taylor Standard model, the ratio is much closer to one. These seemingly contradictory findings may be due to the difference in prismatic coefficient (C_P). The "stock model" has a prismatic coefficient of 0.678 whereas the T-ARC has a prismatic coefficient of 0.695.

The effect of C_P on resistance can be shown in Taylor's "Speed and Power", Reference 1, Appendix B. For a ship with displacement-length ratio of 150 for instance, at speed -length ratio of 0.8, a reduction of 0.02 in prismatic coefficient will result in a 9% reduction in Rr/ (pounds residuary resistance per ton displacement).

Therefore, a slight increase of midship section coefficient of T-ARC, which can be accomplished without affecting the basic hull space requirements, will in effect reduce the C_P of T-ARC. This in turn may improve the resistance characteristics of T-ARC.

At the time resistance experiments 1 and 2 were conducted, the model was constructed with sharp forward sides of stem. The Question was raised as to whether this sharp edge would adversely affect the resistance. Therefore, the model was refinished to remove the sharp edges at the stern before subsequent tests were performed, and experiment 1 was repeated with the rounded stern on experiment 3. In comparing results of experiment 1 and 3, no difference in resistance was found.

The affects of various thruster openings and gratings of the thrusters, on resistance are compared at two speeds as shown in Table 15. The effectiveness of the grating in reducing the resistance can

be seen when comparing Tests 4 and 5, or Tests 2 and 3.

The bottom thruster (Thrusters Numbers 5 and 6) cause little increase in resistance. However, it should be noted that the bottom thrusters as tested do not allow water to flow through them. Therefore, the results do not reflect the actual behavior of the thrusters.

In the same vein, all the thrusters used in these experiments are without propulsors. Therefore the results presented here are for comparison only and should not be construed as actual resistance of the T-ARC for each of the arrangements of the thrusters with the propulsor installed. The propulsor in the thruster duct will somewhat restrict the water flow through the duct, therefore, the increase in resistance due to thrusters may not be as great as is shown from these experiments.

The skeg of T-ARC caused an 11 percent increase in resistance through the speed range. This represents a large percent of total drag. Effort should be made to reduce this added drag.

FLOW OBSERVATION EXPERIMENTS

At the design speed of 15 knots the flow at the bow generally appeared to follow the contour of the hull. At 8 knots, however, some separations were observed. At the stern, especially around the end of the skeg and between the rudders, the flow appeared to be stagnating at all speeds tested.

The flow around the thrusters before installing the gratings was quite disturbed; it became fairly smooth after the gratings were installed especially at the speed equivalent to 15 knots full scale as shown in Figure 26. Here again it should be remembered that the thrusters are without propulsor.

From the flow observation, it can be concluded that the flow pattern of T-ARC may be improved by modifying the skeg and stern shape to avoid flow separation. The resistance characteristics would also be improved as the result of a smoother flow around the hull.

REFERENCE

1. Taylor, D. W., "The Speed and Power of Ships", 3rd edition U. S. Government Printing Office, Washington, D. C. (1943).

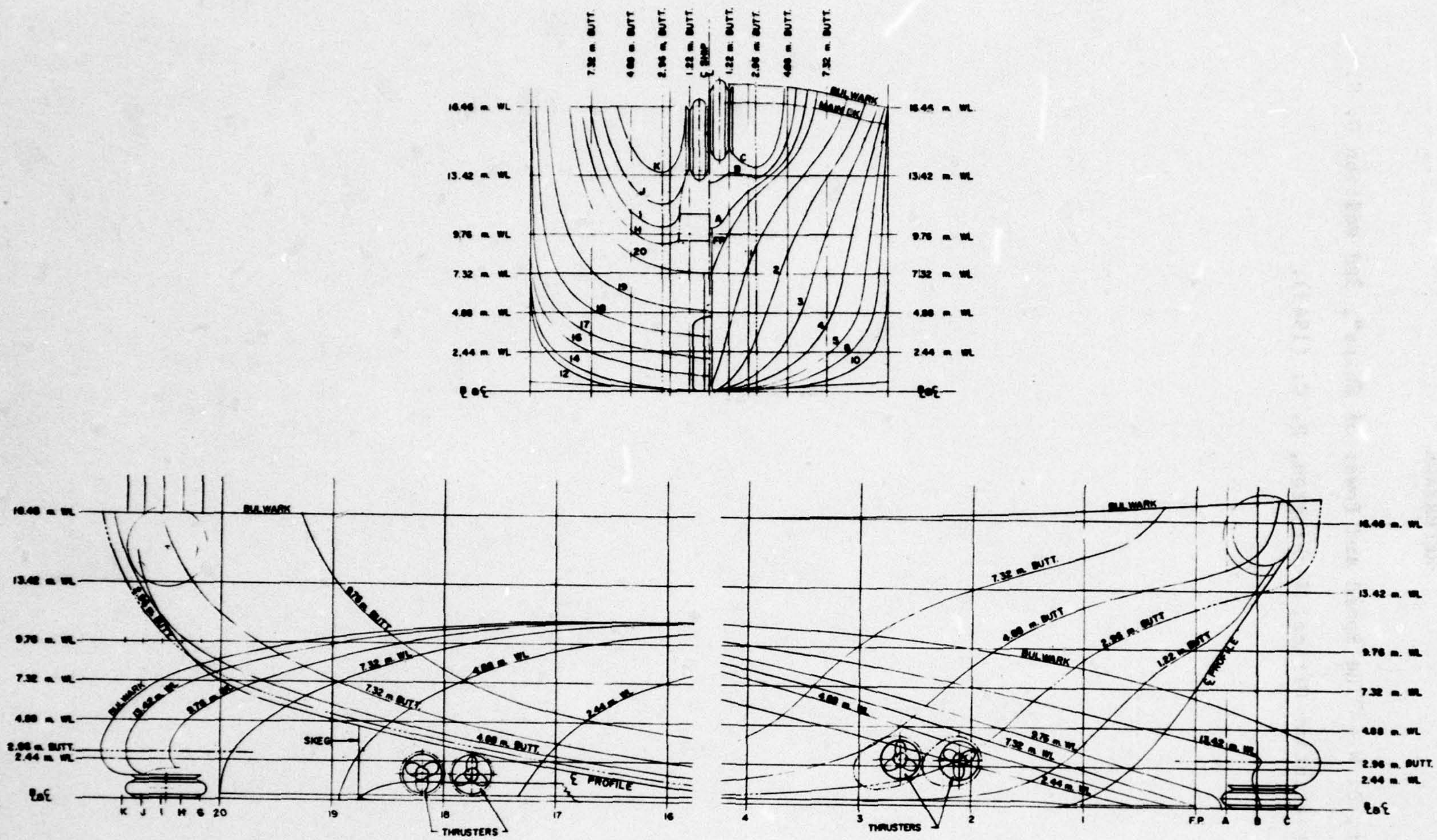

FIGURE 1. ABBREVIATED LINES OF T-ARC, MODEL 5364

MODEL 5364

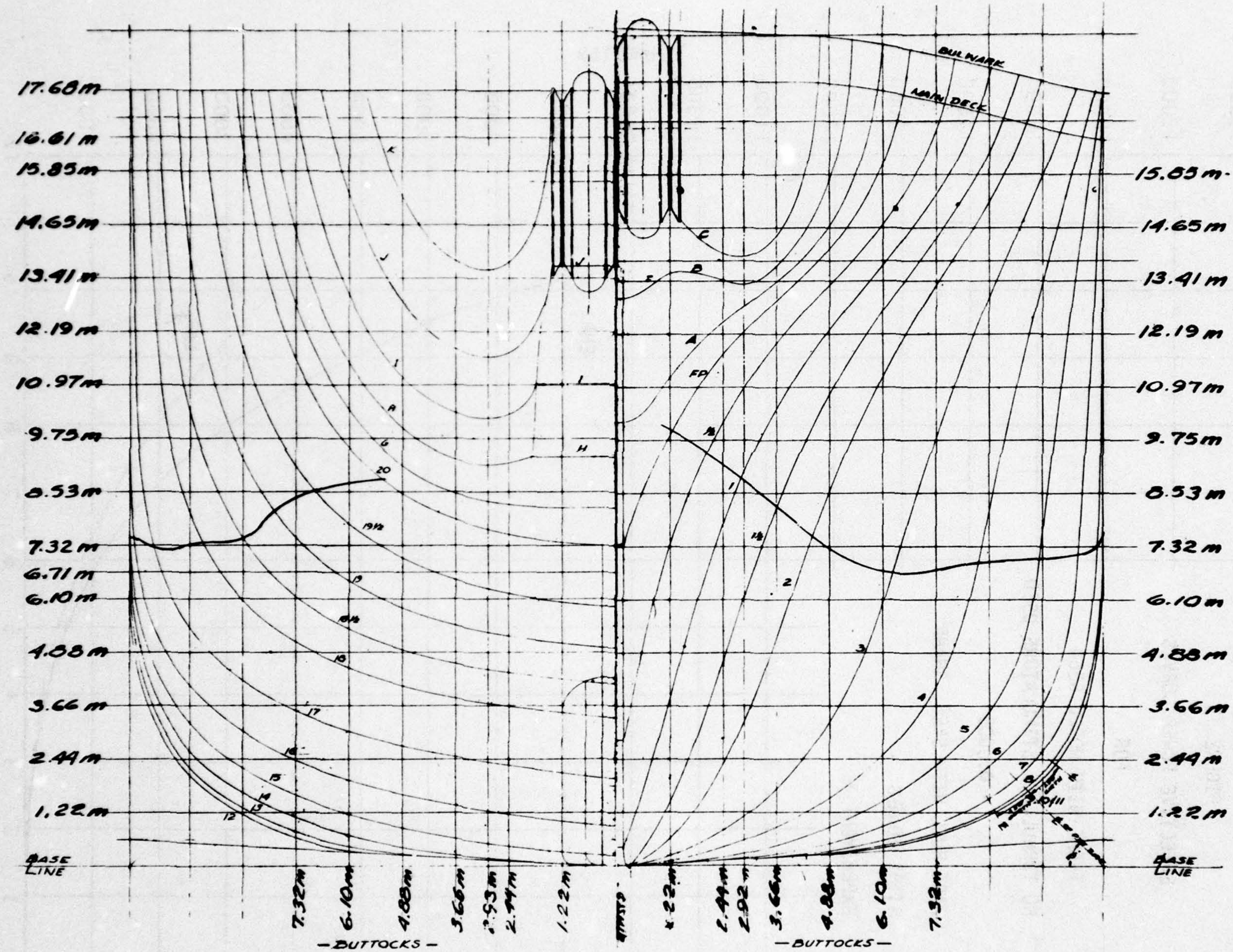

FIGURE 2. WAVE PROFILE TRACE OF T-ARC, MODEL 5364, AT 15 KNOTS SHIP SPEED.

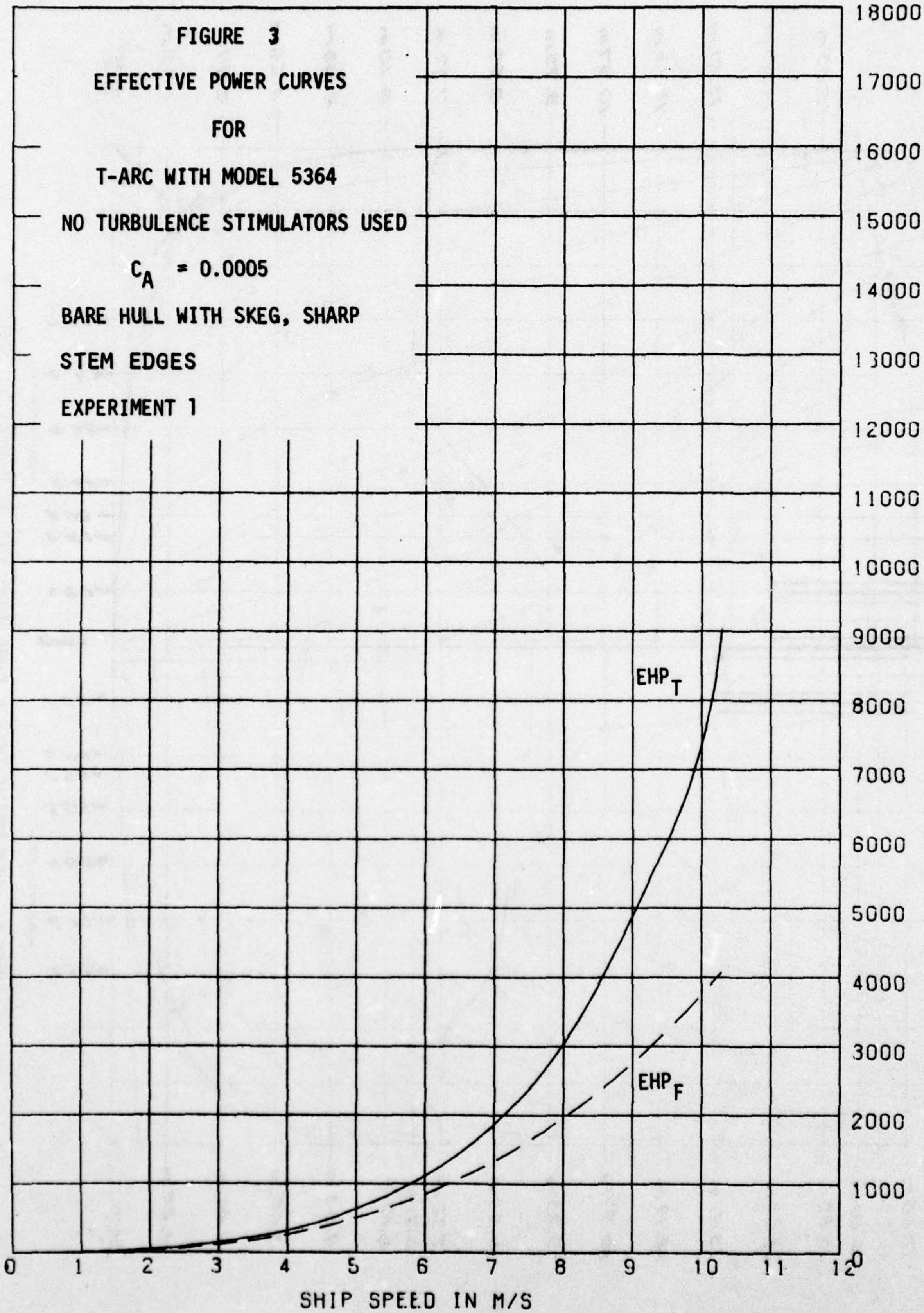
FIGURE 3
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
BARE HULL WITH SKEG, SHARP
STEM EDGES
EXPERIMENT 1
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
KILOWATT
0 1 2 3 4 5 6 7 8 9 10 11 12
SHIP SPEED IN M/S

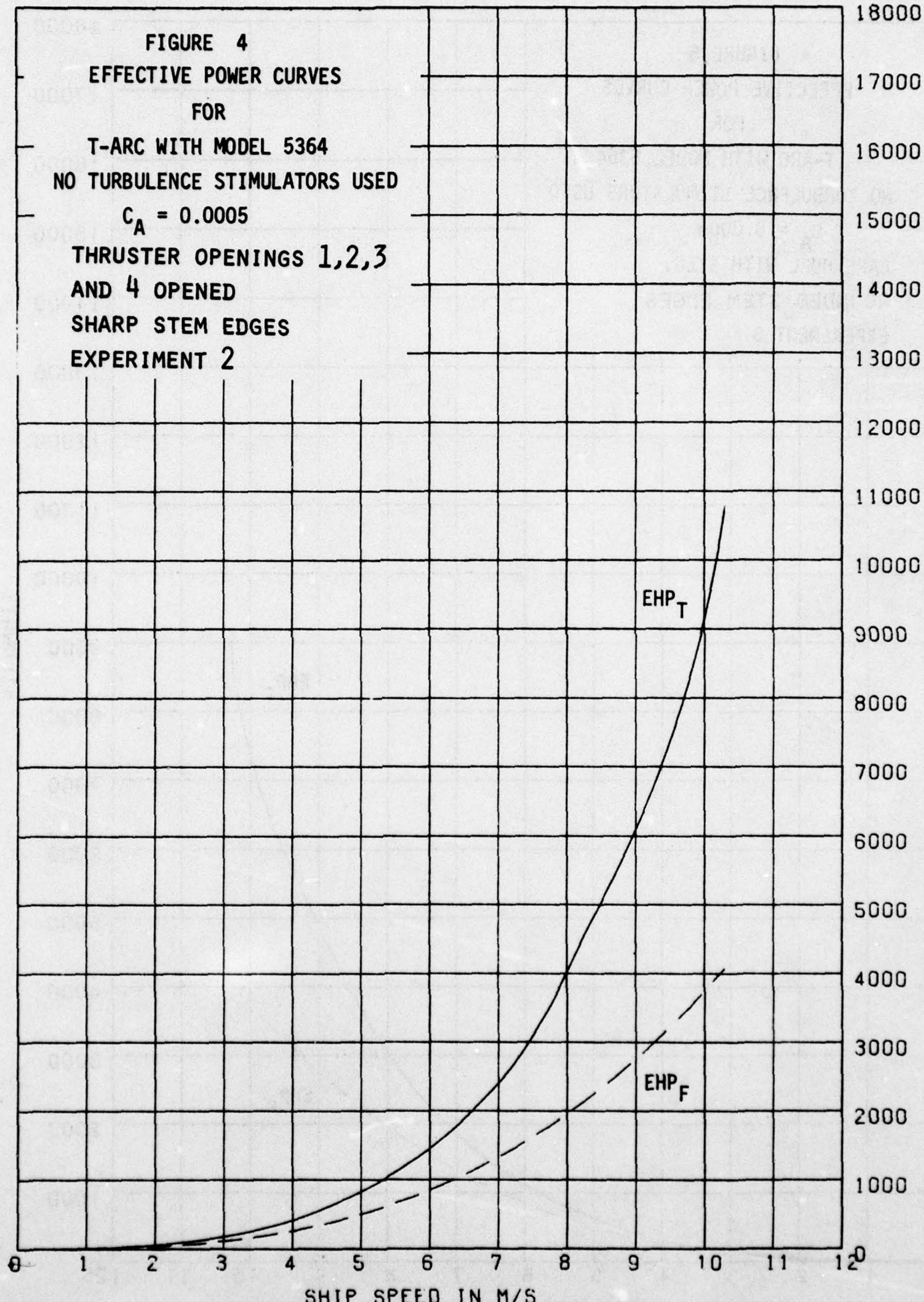
FIGURE 4
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENINGS 1,2,3
AND 4 OPENED
SHARP STEM EDGES
EXPERIMENT 2
EHP_T
EHP_F
0 1 2 3 4 5 6 7 8 9 10 11 12
SHIP SPEED IN M/S
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000
KILOWATT

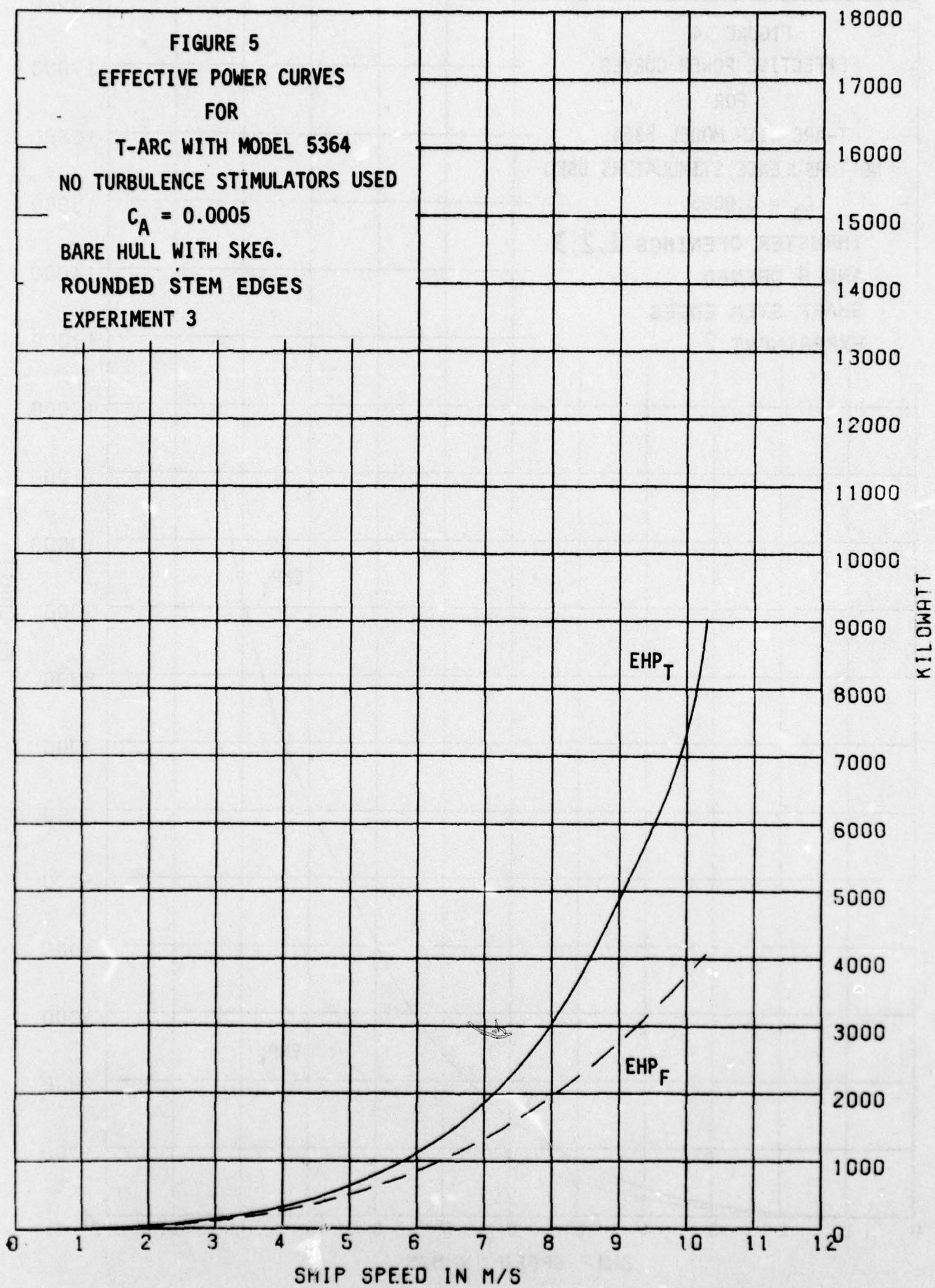
FIGURE 5
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
BARE HULL WITH SKEG.
ROUNDED STEM EDGES
EXPERIMENT 3
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
KILOWATT
0
1
2
3
4
5
6
7
8
9
10
11
12
SHIP SPEED IN M/S

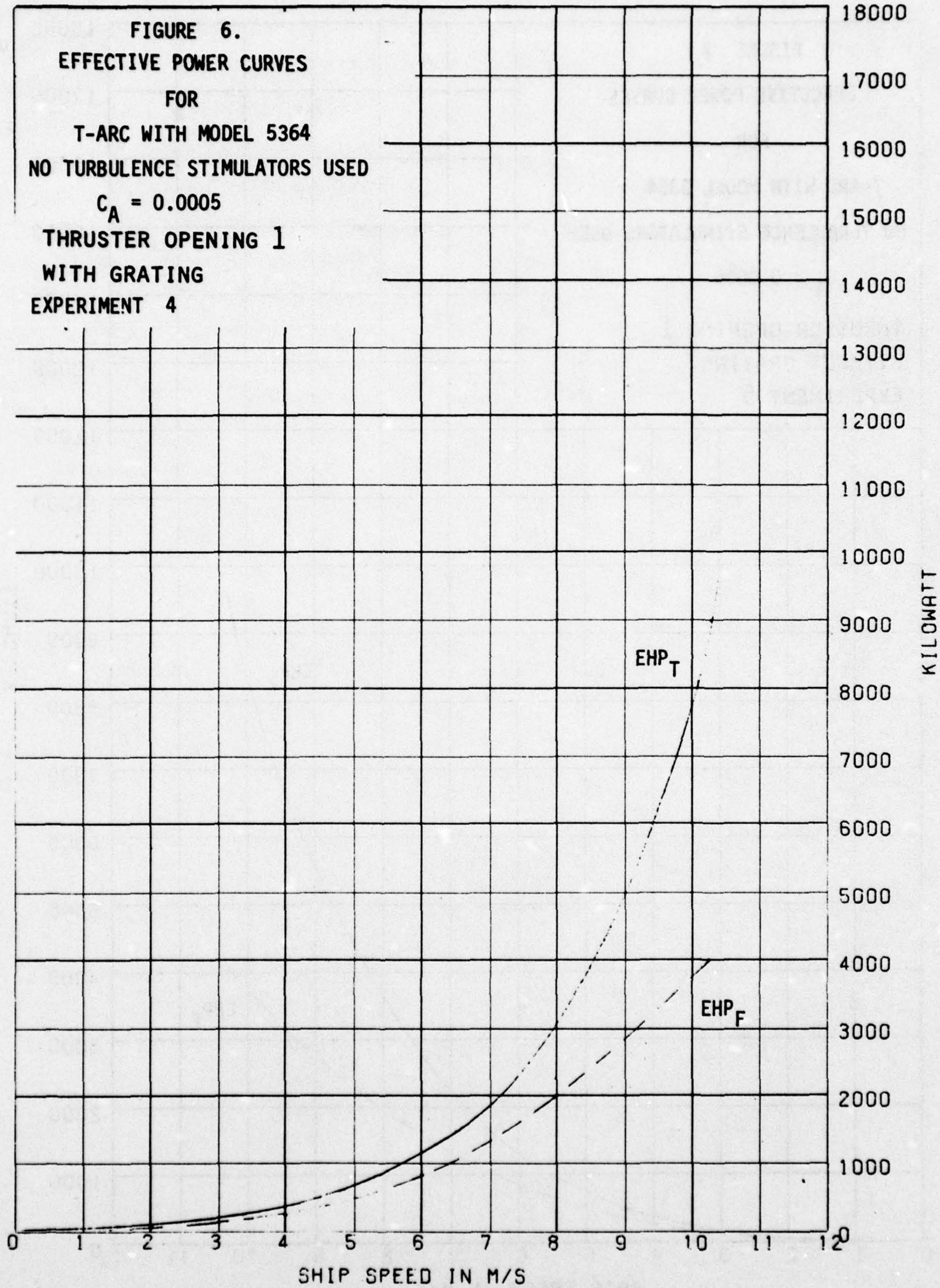
FIGURE 6.
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENING 1
WITH GRATING
EXPERIMENT 4
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
KILOWATT
0
1
2
3
4
5
6
7
8
9
10
11
12
SHIP SPEED IN M/S

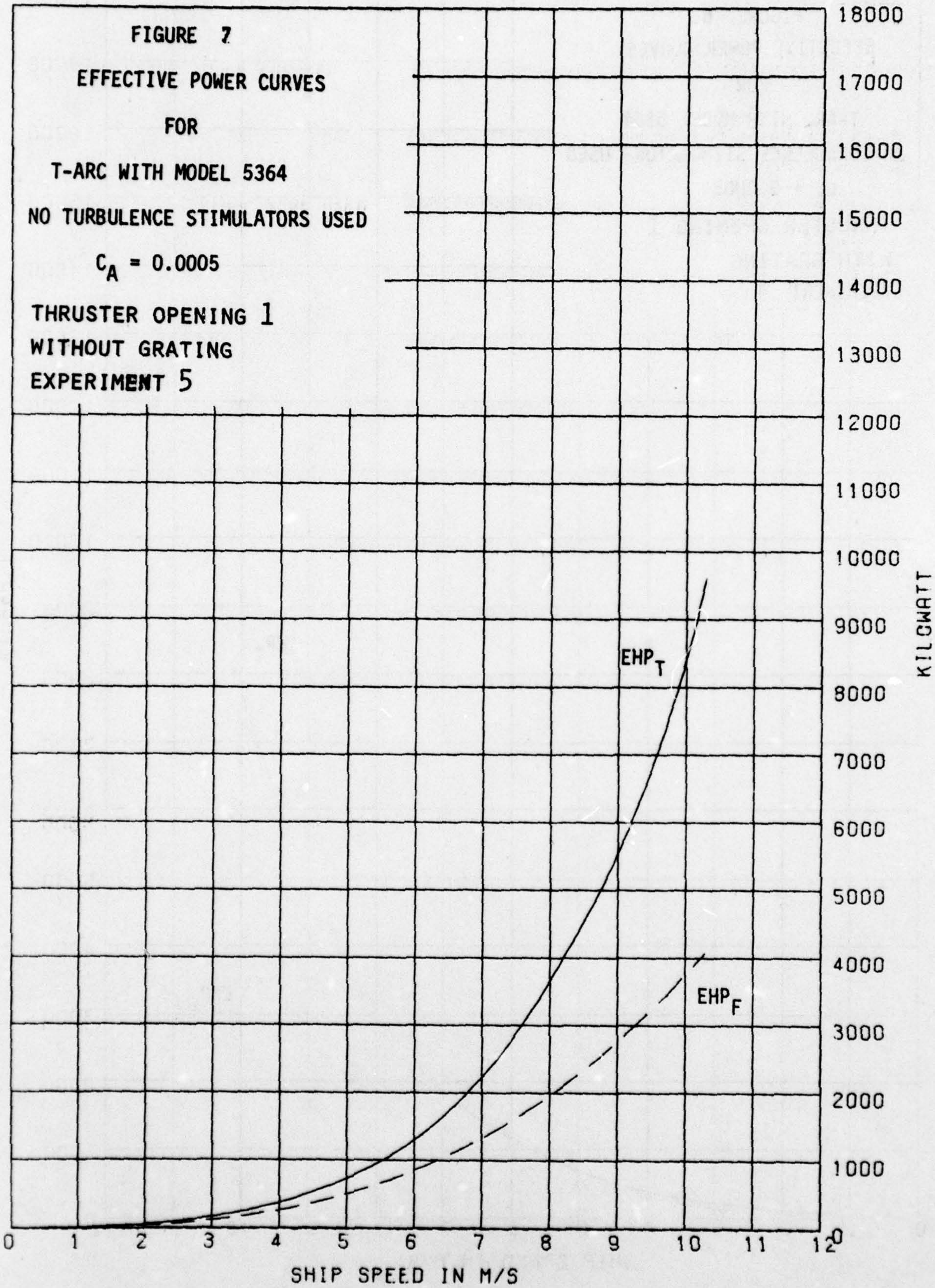

FIGURE 7
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENING 1
WITHOUT GRATING
EXPERIMENT 5
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
KILOWATT
0 1 2 3 4 5 6 7 8 9 10 11 12
SHIP SPEED IN M/S

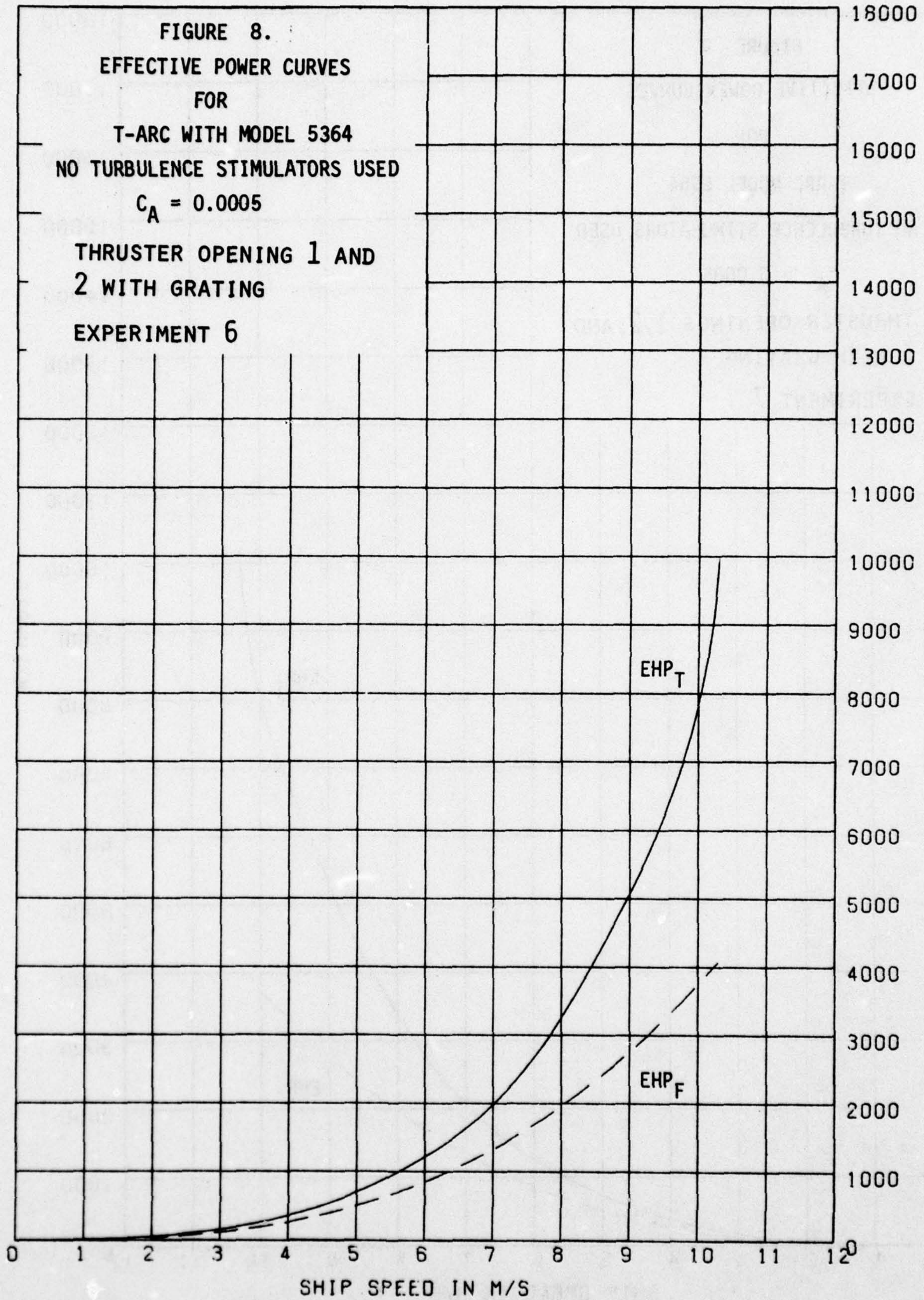
FIGURE 8.
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENING 1 AND
2 WITH GRATING
EXPERIMENT 6
EHP_T
EHP_F
KILOWATT
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10 11 12
SHIP SPEED IN M/S

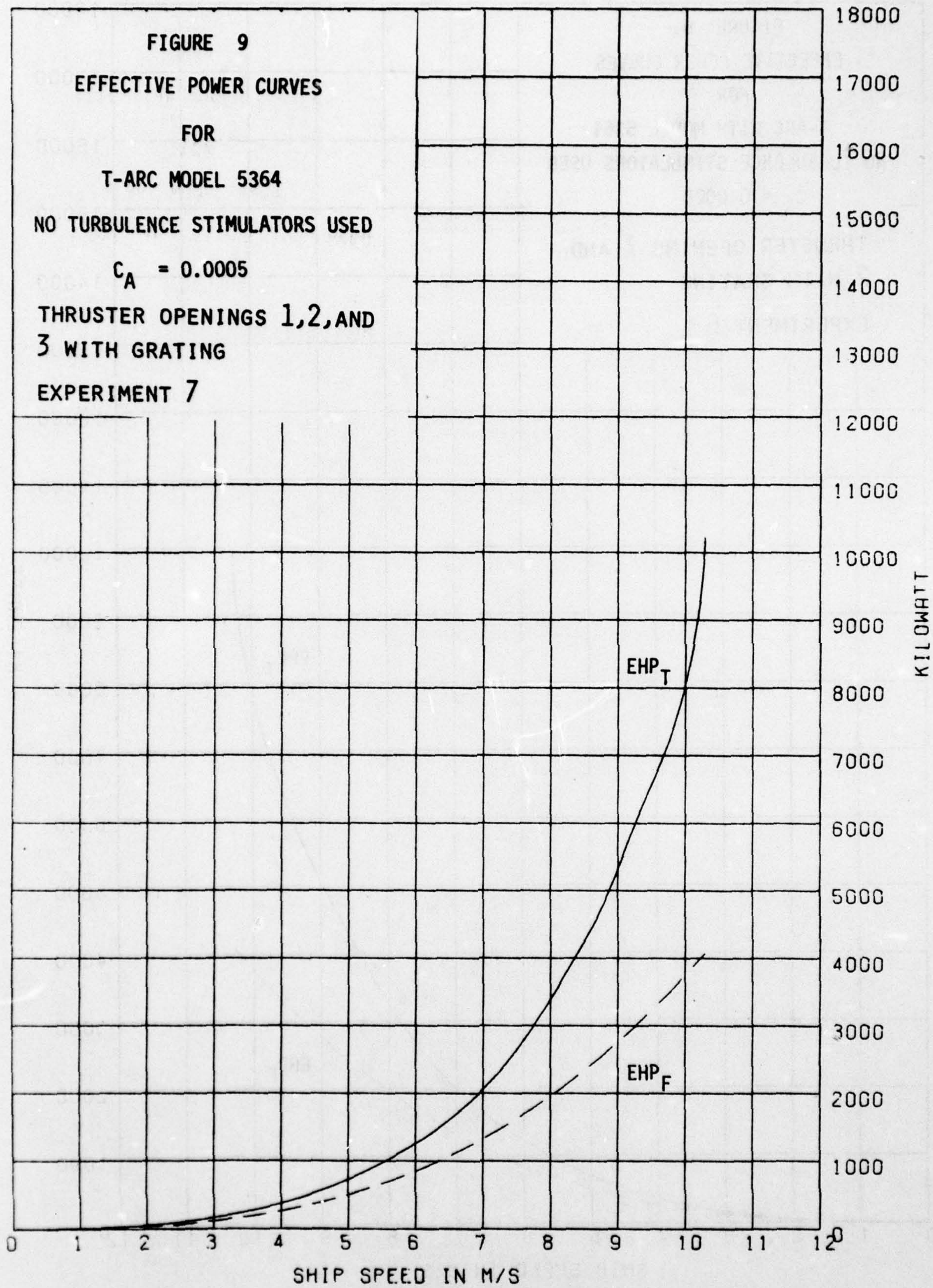

FIGURE 9
EFFECTIVE POWER CURVES
FOR
T-ARC MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENINGS 1,2,AND
3 WITH GRATING
EXPERIMENT 7
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
KILOWATT
0
1
2
3
4
5
6
7
8
9
10
11
12
SHIP SPEED IN M/S

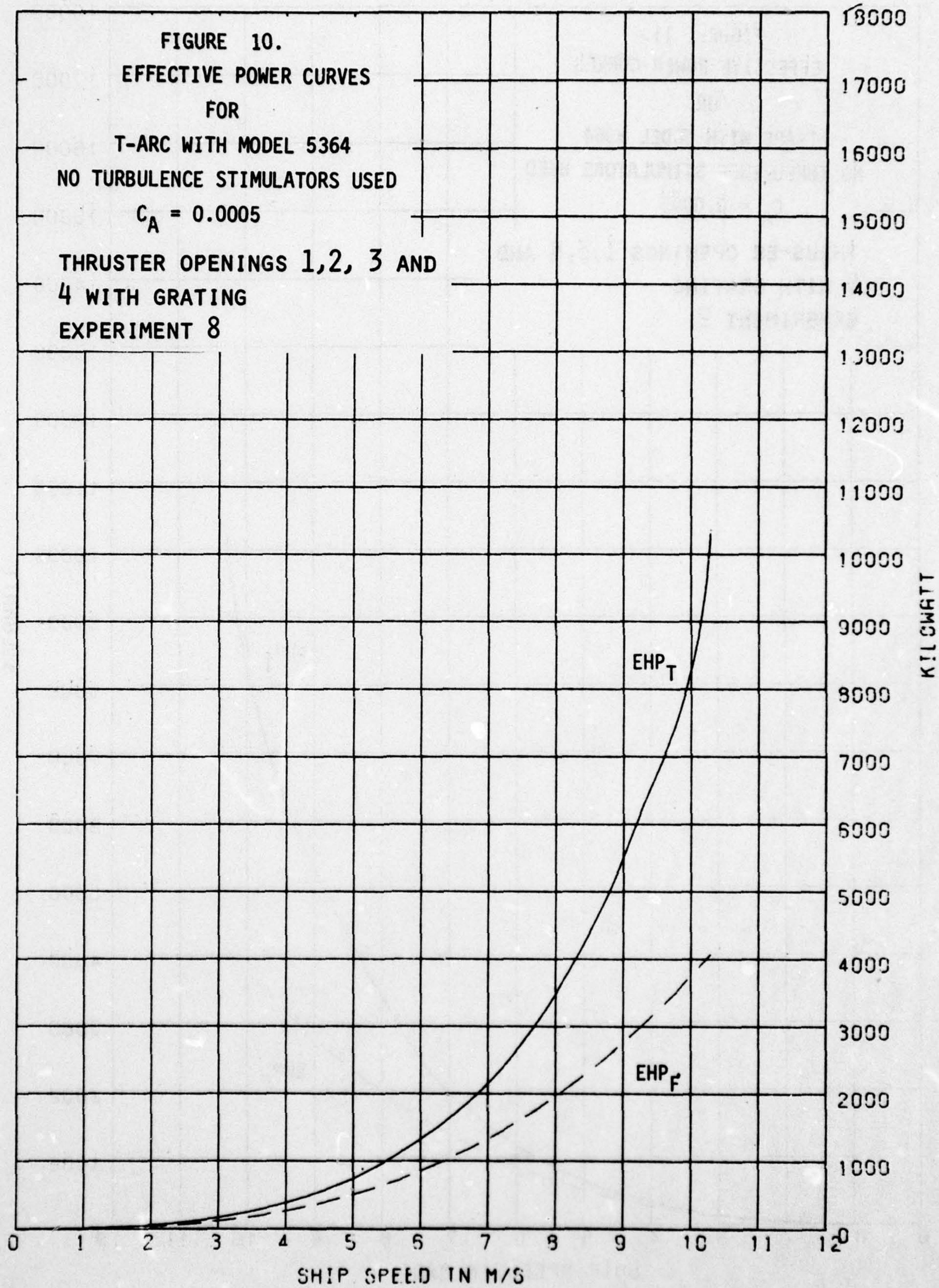
FIGURE 10.
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENINGS 1,2, 3 AND
4 WITH GRATING
EXPERIMENT 8
EHP_T
EHP_F
0 1 2 3 4 5 6 7 8 9 10 11 12
SHIP SPEED IN M/S
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000
KILOWATT

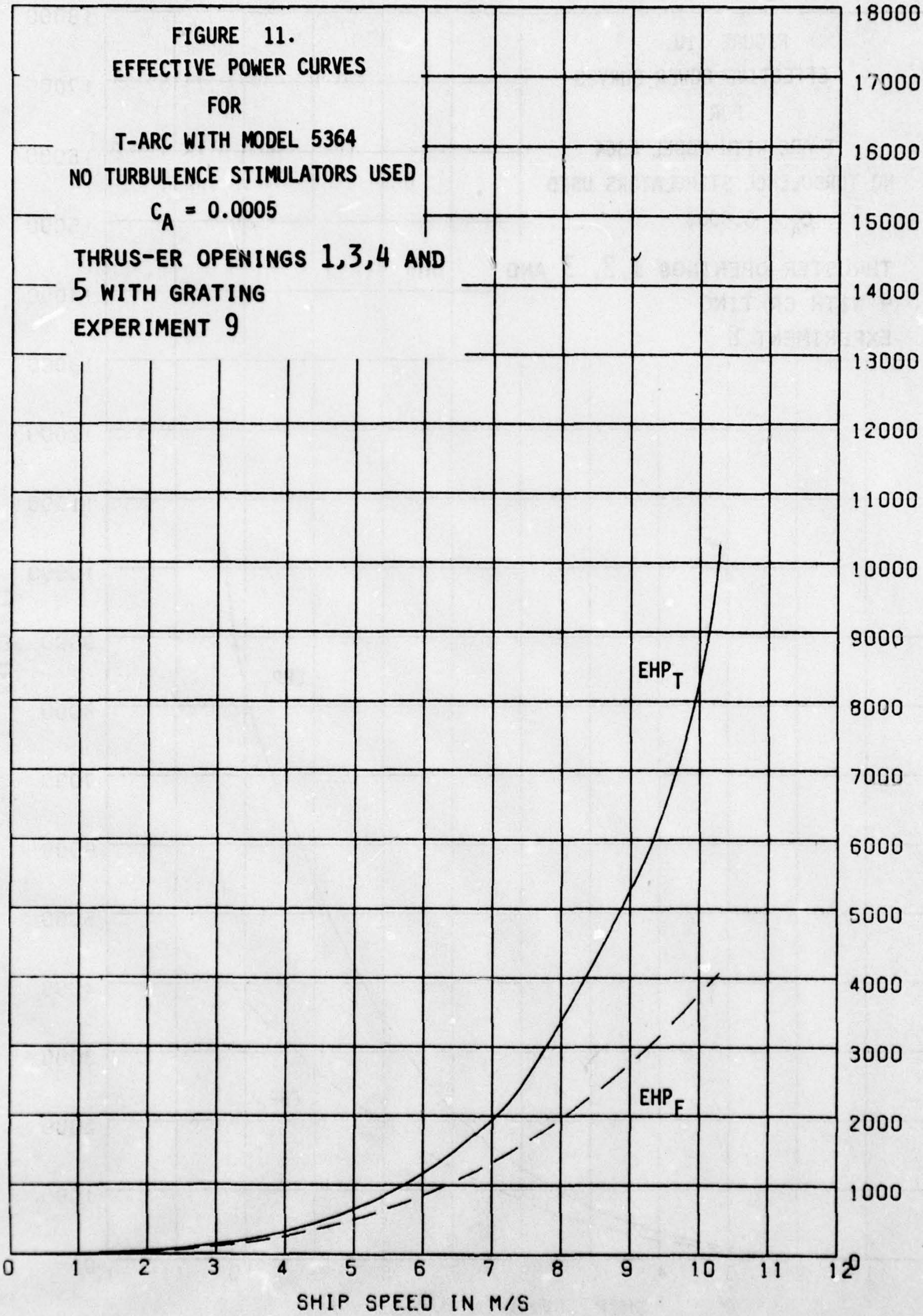
FIGURE 11.
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUS-ER OPENINGS 1,3,4 AND
5 WITH GRATING
EXPERIMENT 9
EHP_T
EHP_E
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
KILOWATT
0 1 2 3 4 5 6 7 8 9 10 11 12
SHIP SPEED IN M/S

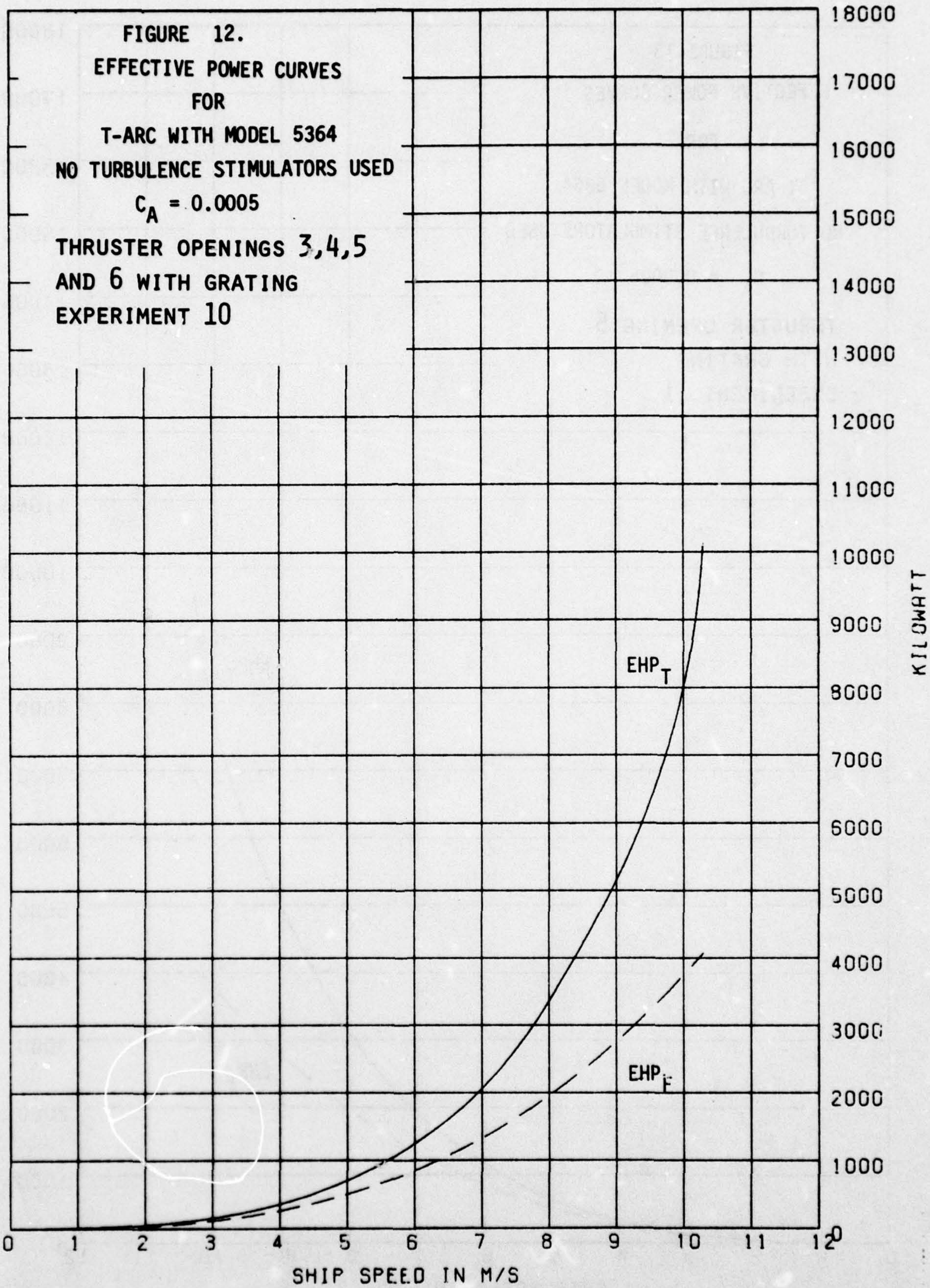
FIGURE 12.
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
$C_A = 0.0005$
THRUSTER OPENINGS 3,4,5
AND 6 WITH GRATING
EXPERIMENT 10
EHP_T
EHP_E
0 1 2 3 4 5 6 7 8 9 10 11 12
SHIP SPEED IN M/S
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000
KILOWATT

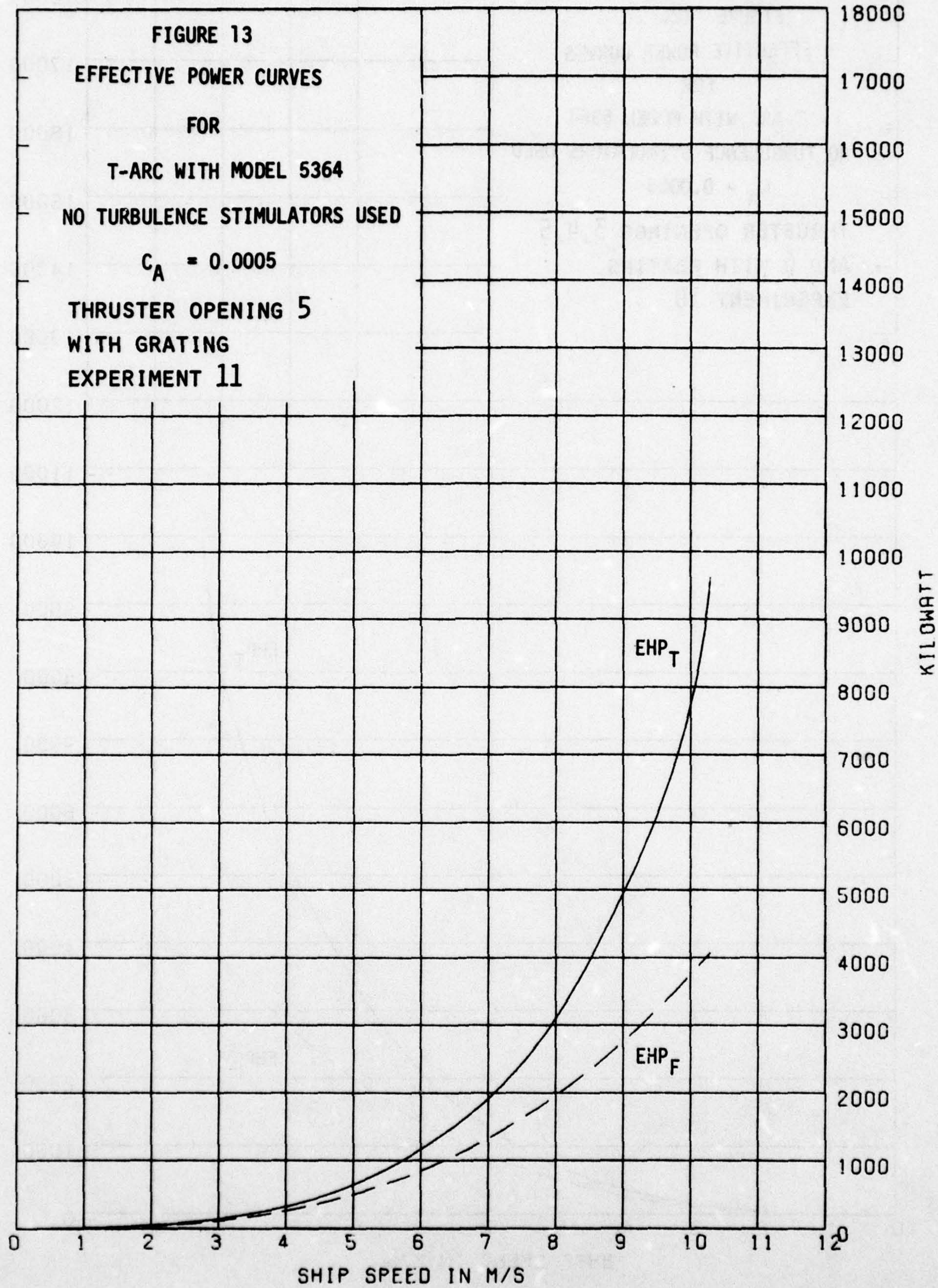
FIGURE 13
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENING 5
WITH GRATING
EXPERIMENT 11
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
KILOWATT
0
1
2
3
4
5
6
7
8
9
10
11
12
SHIP SPEED IN M/S

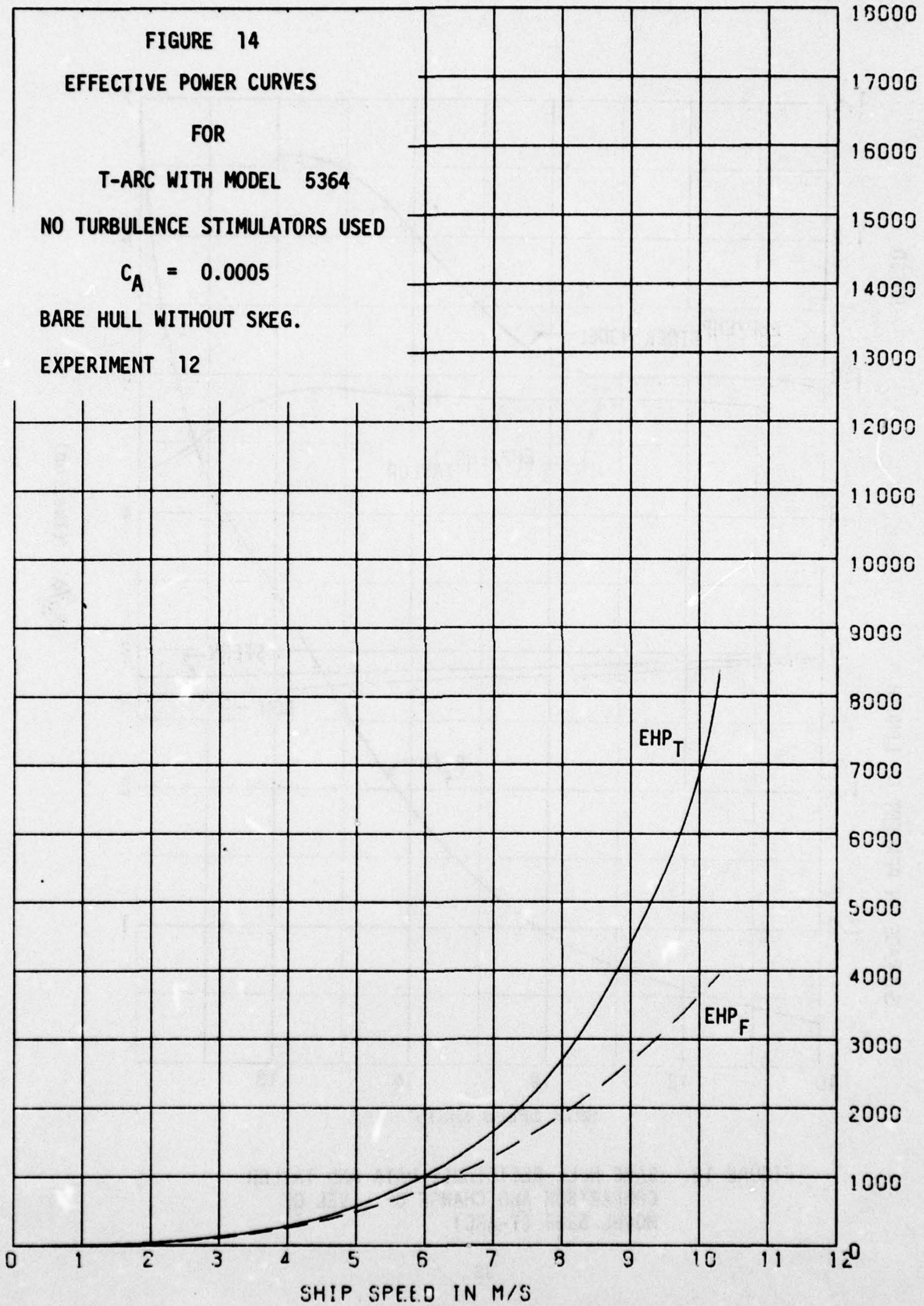

FIGURE 14
EFFECTIVE POWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
BARE HULL WITHOUT SKEG.
EXPERIMENT 12
EHP_T
EHP_F
KILOWATT
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
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4
5
6
7
8
9
10
11
12
SHIP SPEED IN M/S

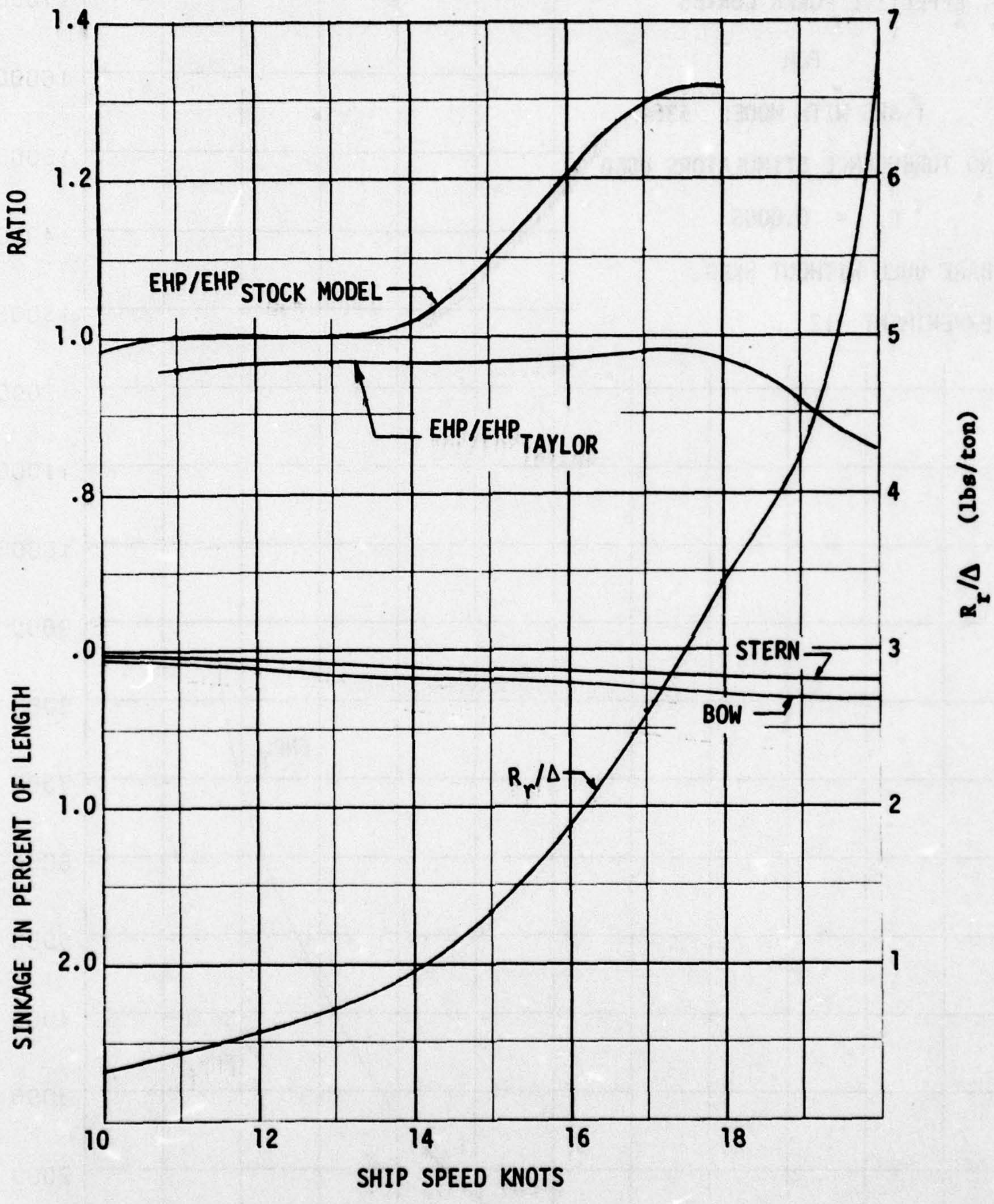


FIGURE 15. BARE HULL RESISTANCE DATA AND TAYLOR COMPARISON AND CHANGE OF LEVEL OF MODEL 5364 (T-ARC)

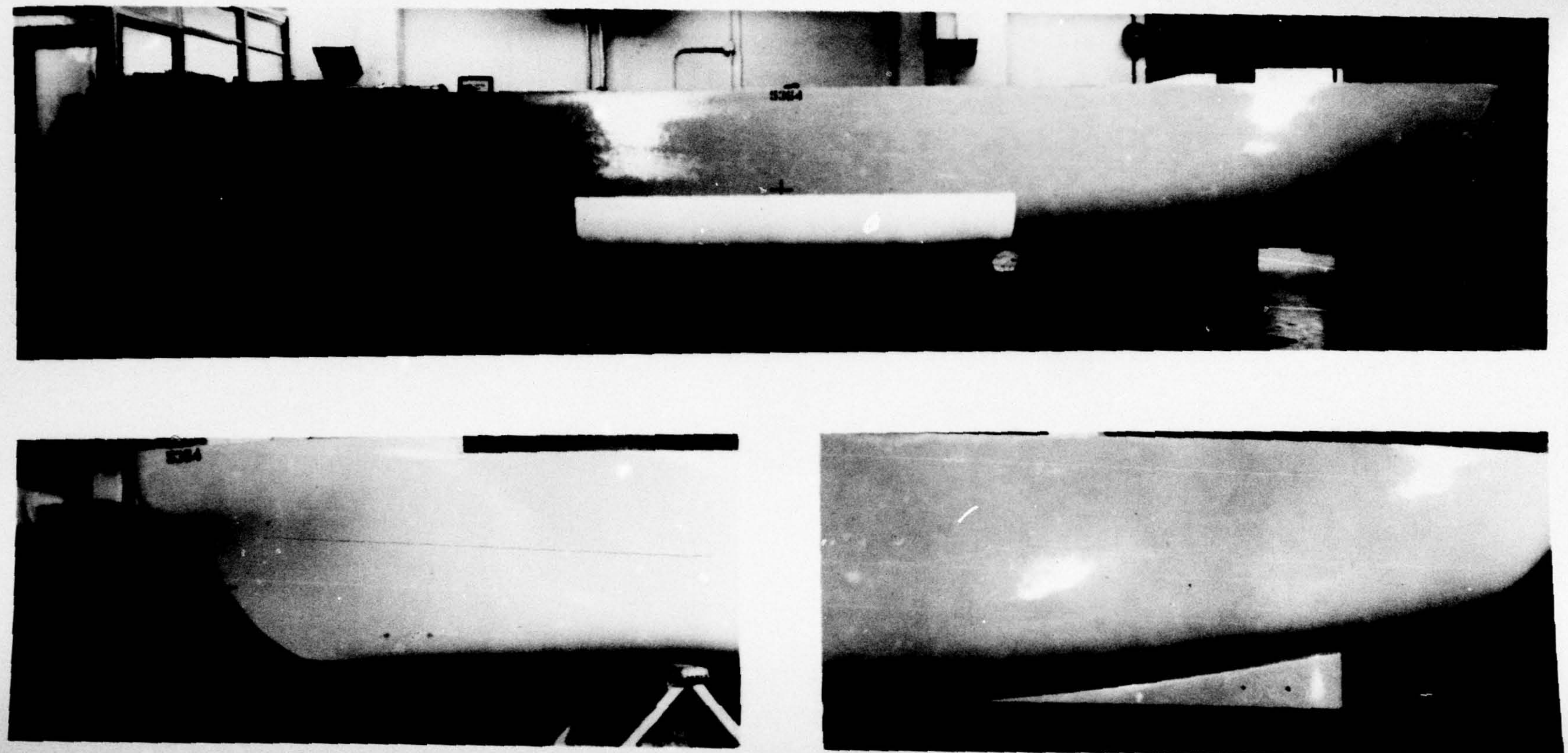


FIGURE 16. FITTING ROOM PHOTOGRAPHS OF T-ARC, MODEL 5364, BARE HULL WITH SKEG.

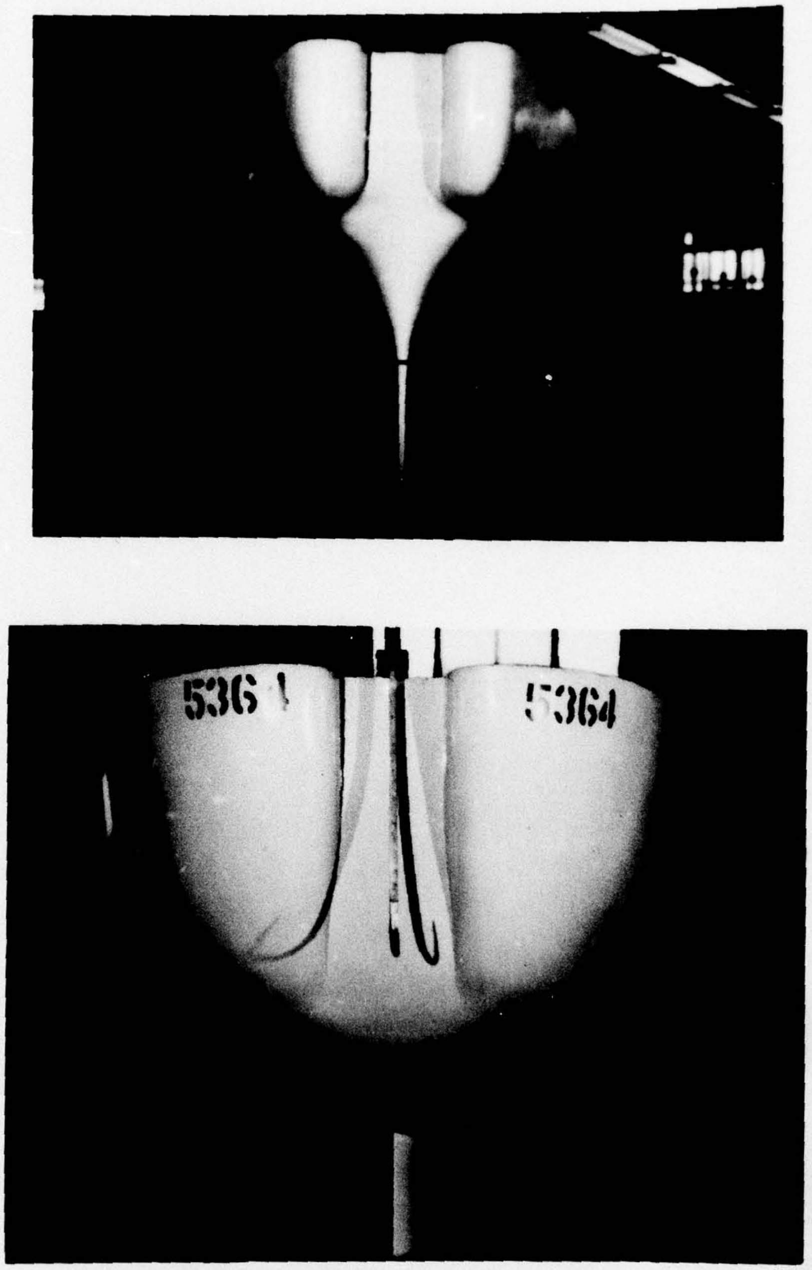


FIGURE 17. BOW AND STERN PHOTOGRAPHS OF T-ARC MODEL 5364.

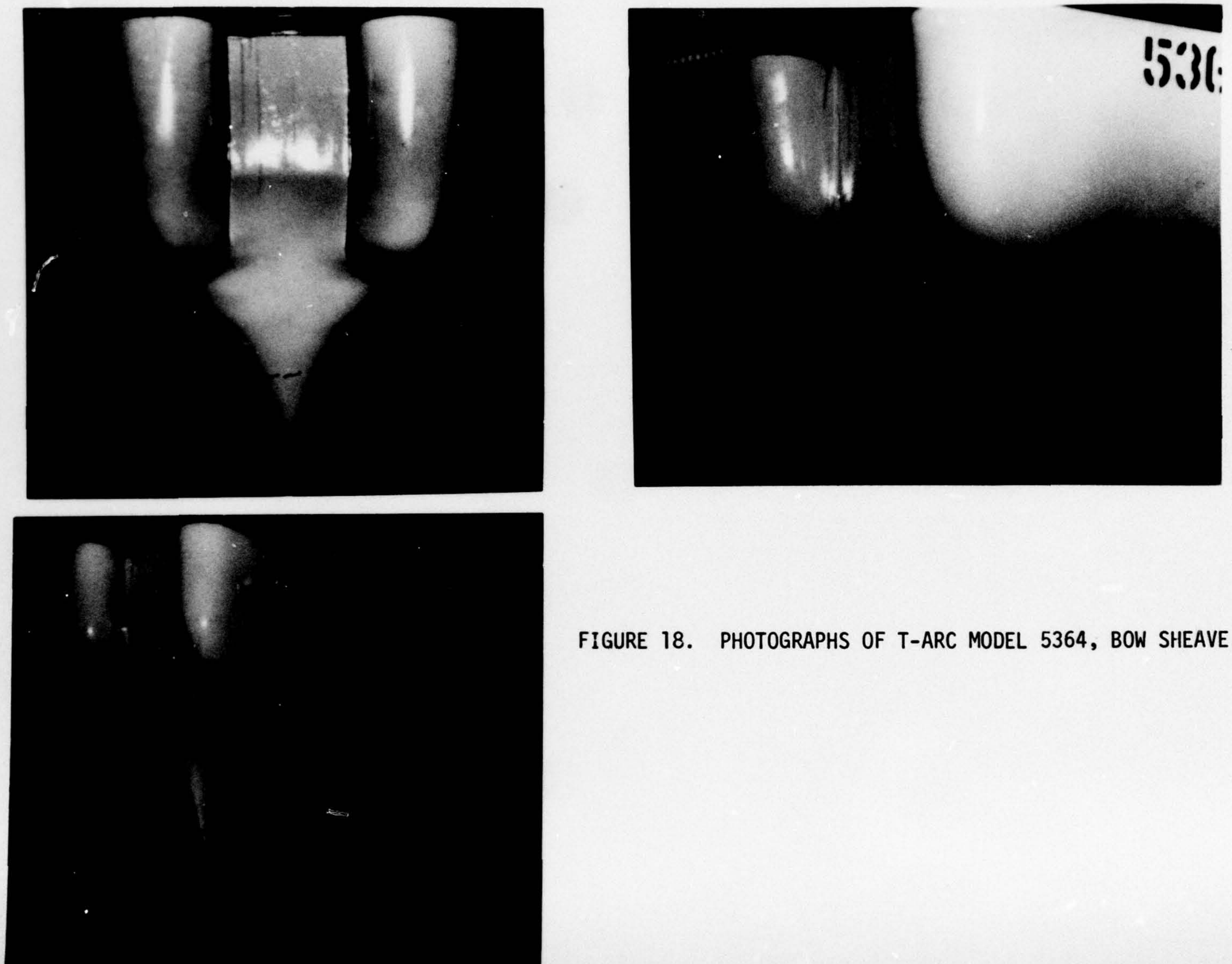


FIGURE 18. PHOTOGRAPHS OF T-ARC MODEL 5364, BOW SHEAVE.

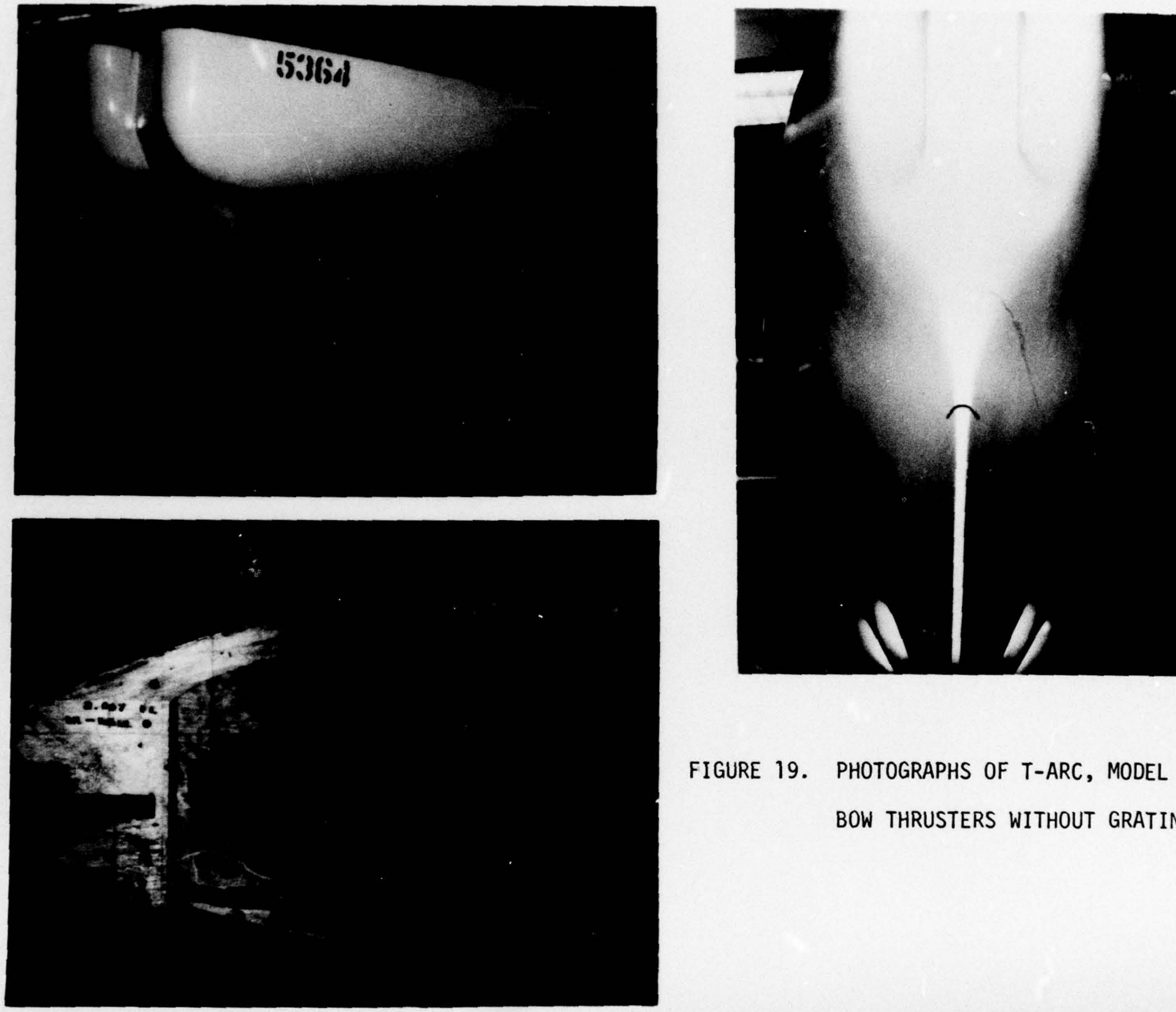


FIGURE 19. PHOTOGRAPHS OF T-ARC, MODEL 5364,
BOW THRUSTERS WITHOUT GRATINGS.

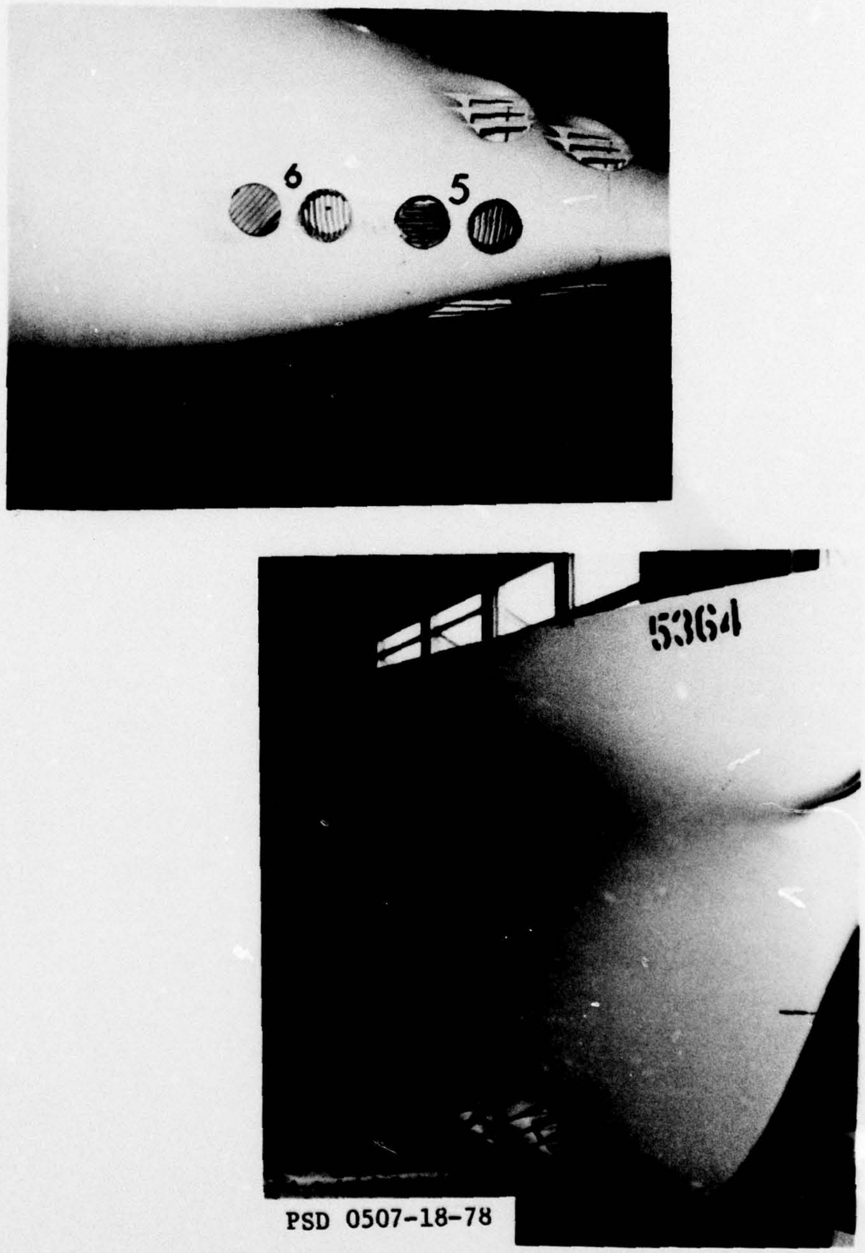
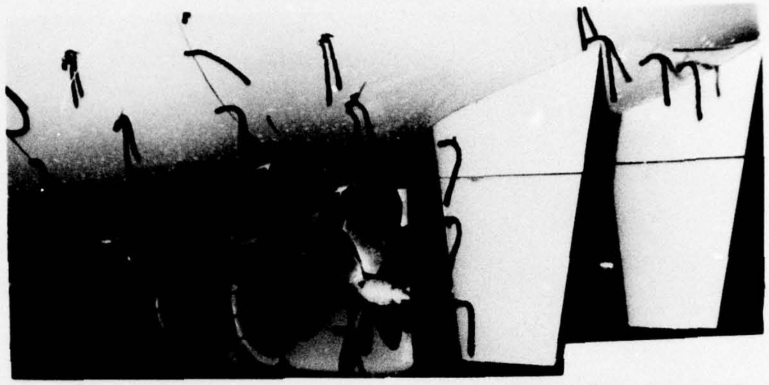


FIGURE 20. PHOTOGRAPHS OF T-ARC, MODEL 5364,
BOW THRUSTERS WITH GRATINGS.



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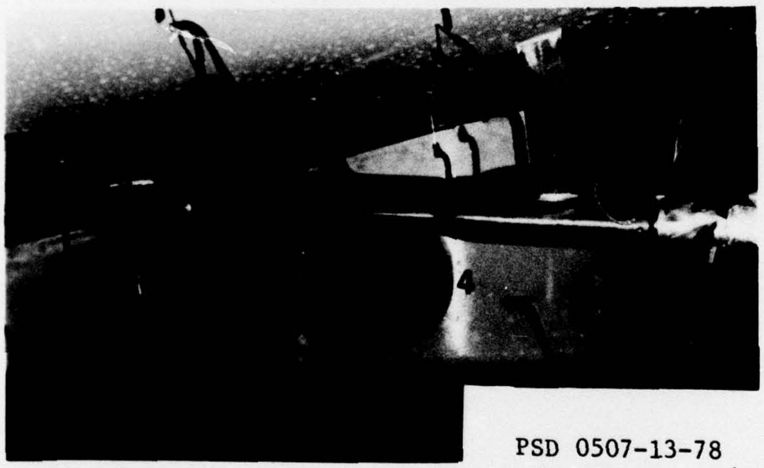

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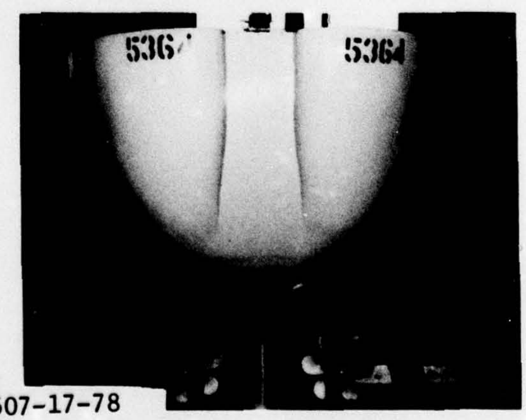


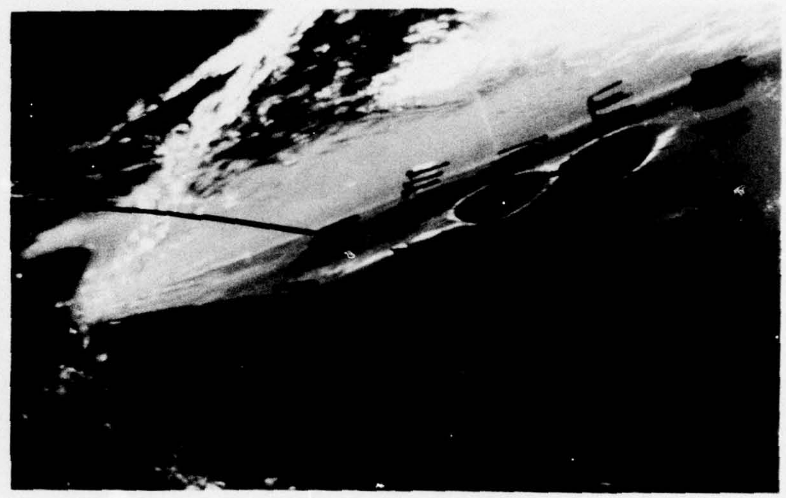
PSD 0507-17-78

FIGURE 21. PHOTOGRAPHS OF T-ARC, MODEL 5364,FULLY APPENDED, AFTER THRUSTERS WITH GRATINGS.

PSD 0506- 8-78

PSD 0506- 7-78

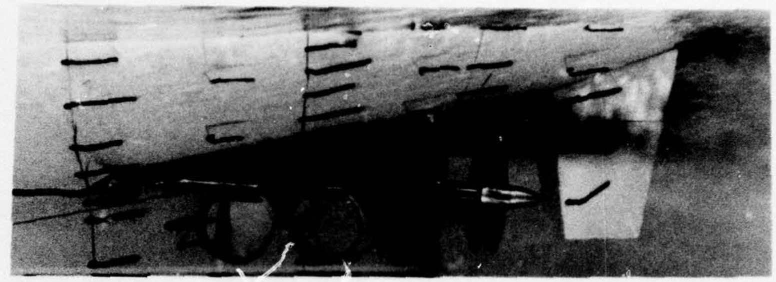
PSD 0506- 9-78



PSD 0506-10-78

FIGURE 22. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL. BOW THRUSTERS WITHOUT GRATINGS. YAW = 0^o, SHIP SPEED = 15 KNOTS.

PSD 0506-17-78



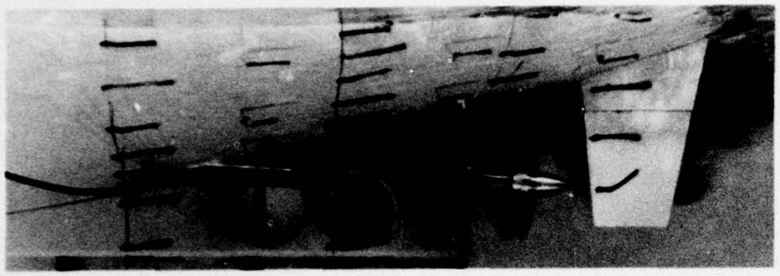
PSD 0506-19-78

PSD 0506-14-78

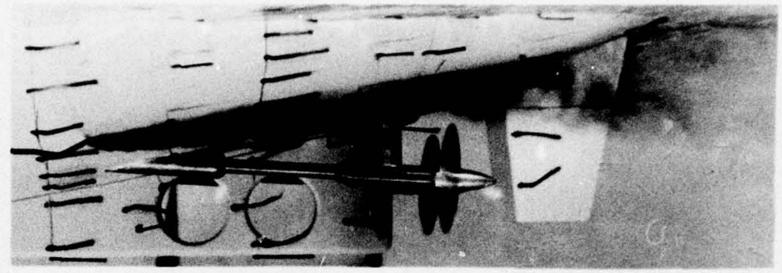
PSD 0506-22-78

FIGURE 23. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL. STERN THRUSTERS WITHOUT GRATINGS.

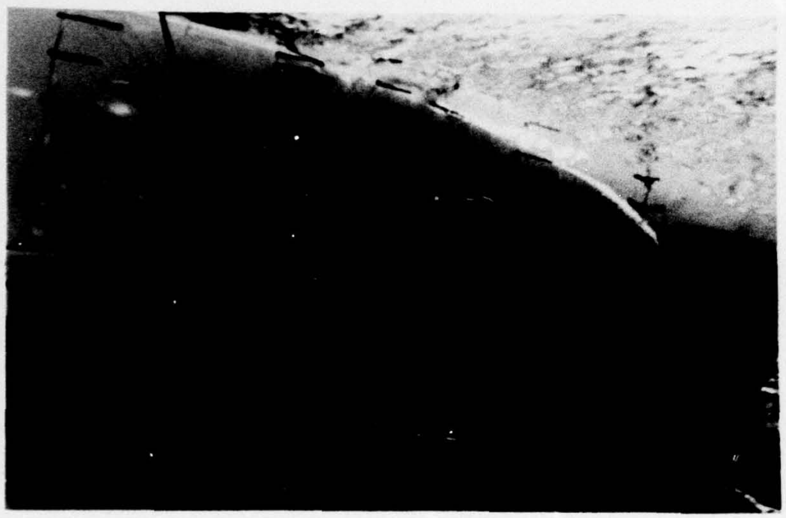
YAW = 0^{o}, SHIP SPEED = 15 KNOTS.



PSD 0506-18-78



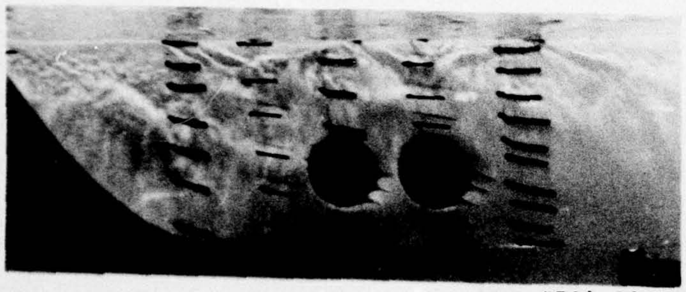
PSD 0506-21-78



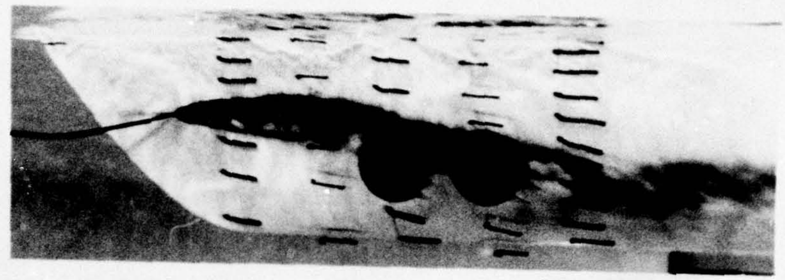
PSD 0506-15-78

PSD 0506-16-78

FIGURE 24. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.
STERN THRUSTERS WITHOUT GRATING.
YAW = 0^o, SHIP SPEED = 15 KNOTS.



PSD 0504-11-78

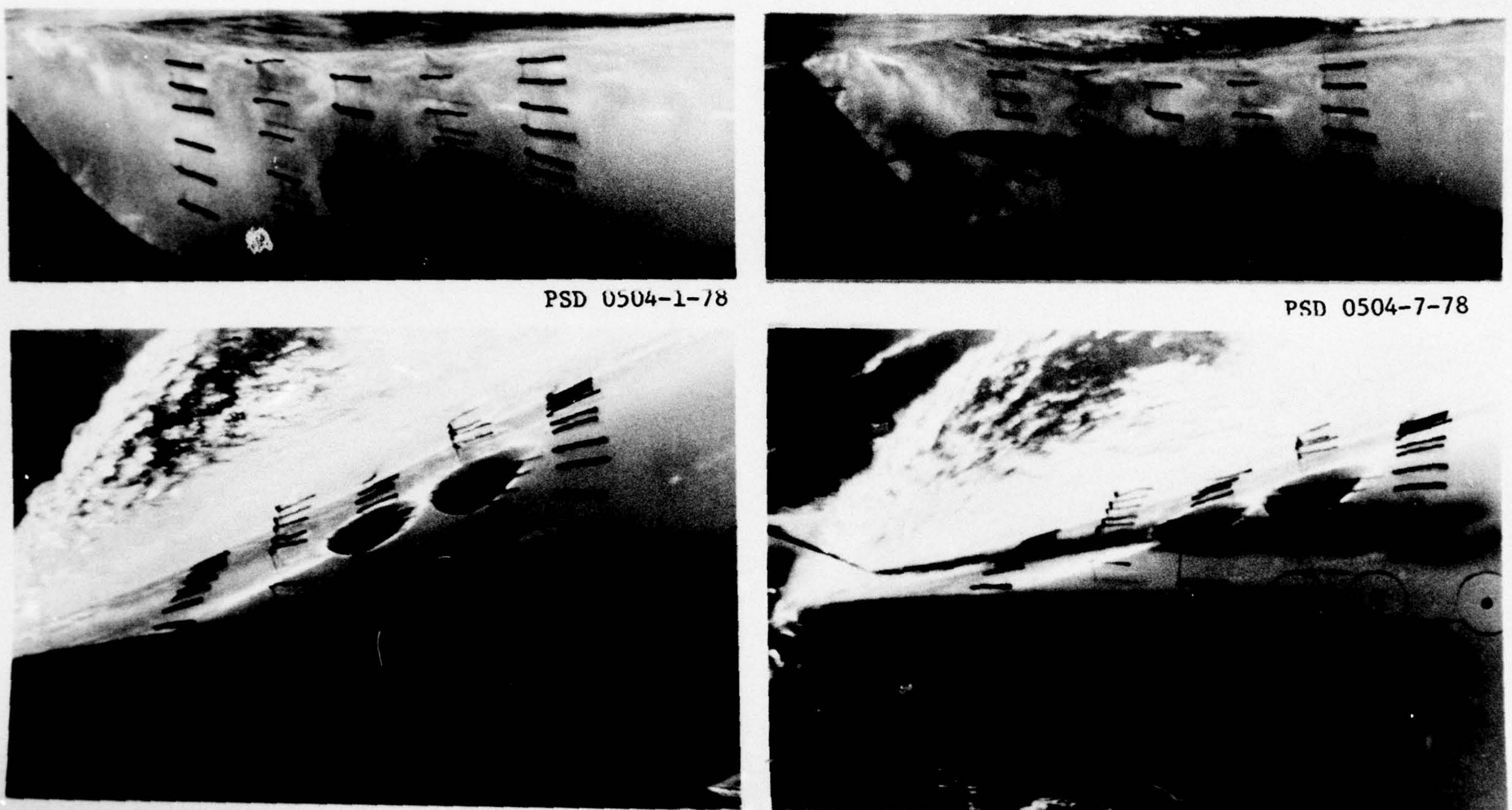


PSD 0504-12-78

PSD 0504-10-78

PSD 0504-15-78

FIGURE 25. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.
YAW = 0^{o}, SHIP SPEED = 8 KNOTS



PSD 0504-1-78

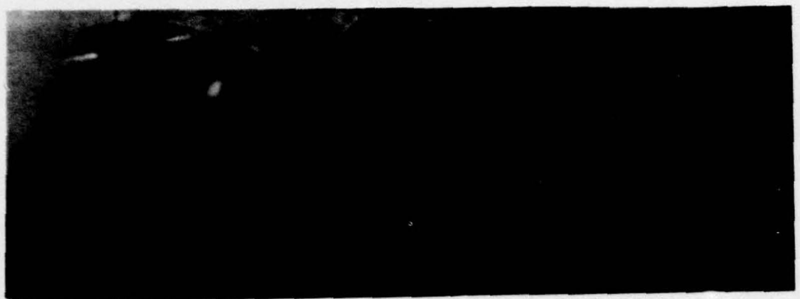
PSD 0504-7-78

PSD 0504-4-78

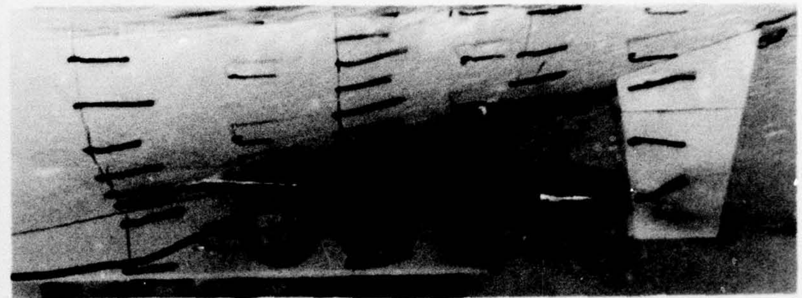
PSD 0504-5-78

FIGURE 26. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL

YAW = 0^{o}. SHIP SPEED = 15 KNOTS



PSD 0504-8-78



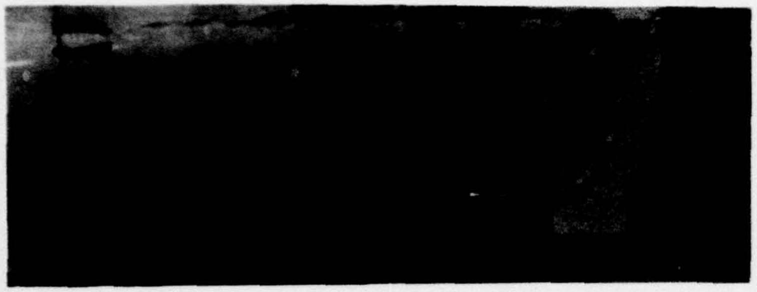
PSD 0506-33-78

PSD 0504-9-78

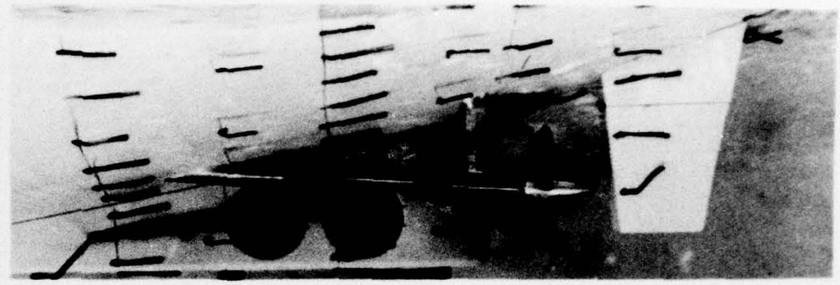
PSD 0506-30-78

FIGURE 27. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

YAW = 0^{o}, SHIP SPEED = 8 KNOTS.



PSD 0505-29-78



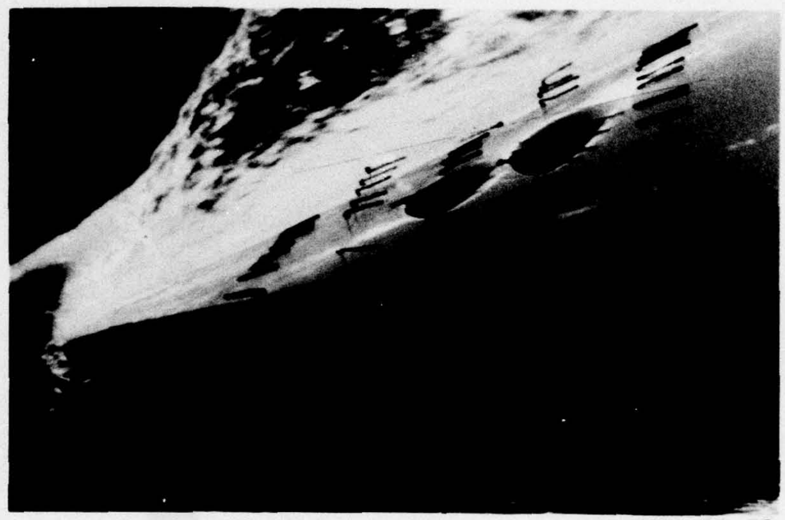
PSD 0506-34-78

PSD 0504-3-78

PSD 0506-36-78

FIGURE 28. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.
YAW = 0^{o}, SHIP SPEED = 15 KNOTS

PSD 0505-32-78

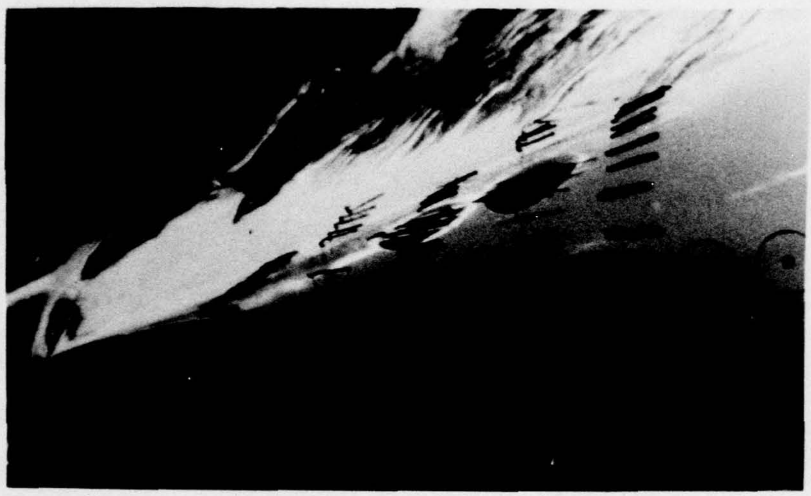


PSD 0505-31-78

FIGURE 29. T-ARC, MODEL 5364 IN CIRDULATING WATER CHANNEL.
YAW = 0^{o}, SHIP SPEED = 8 KNOTS

PSD 0505- 0-78

PSD 0505- 1-78

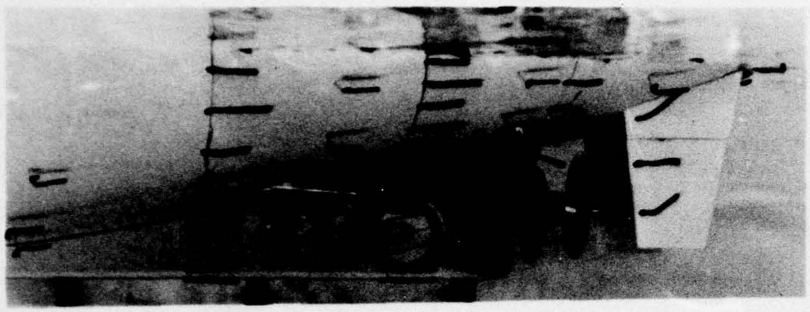


PSD 0504-34-78

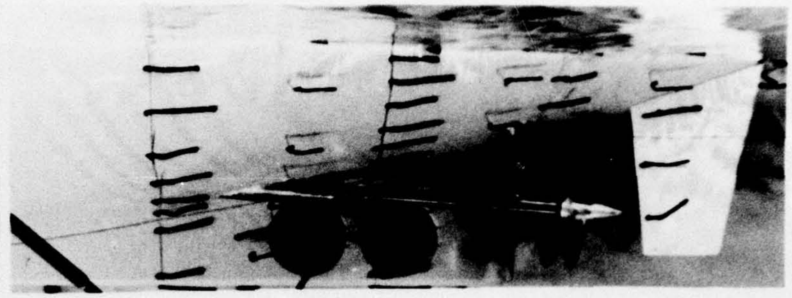
PSD 0505- 4-78

FIGURE 30. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

YAW = 5^{O}PORT. SHIP SPEED = 8 KNOTS.



PSD 0504-32-78



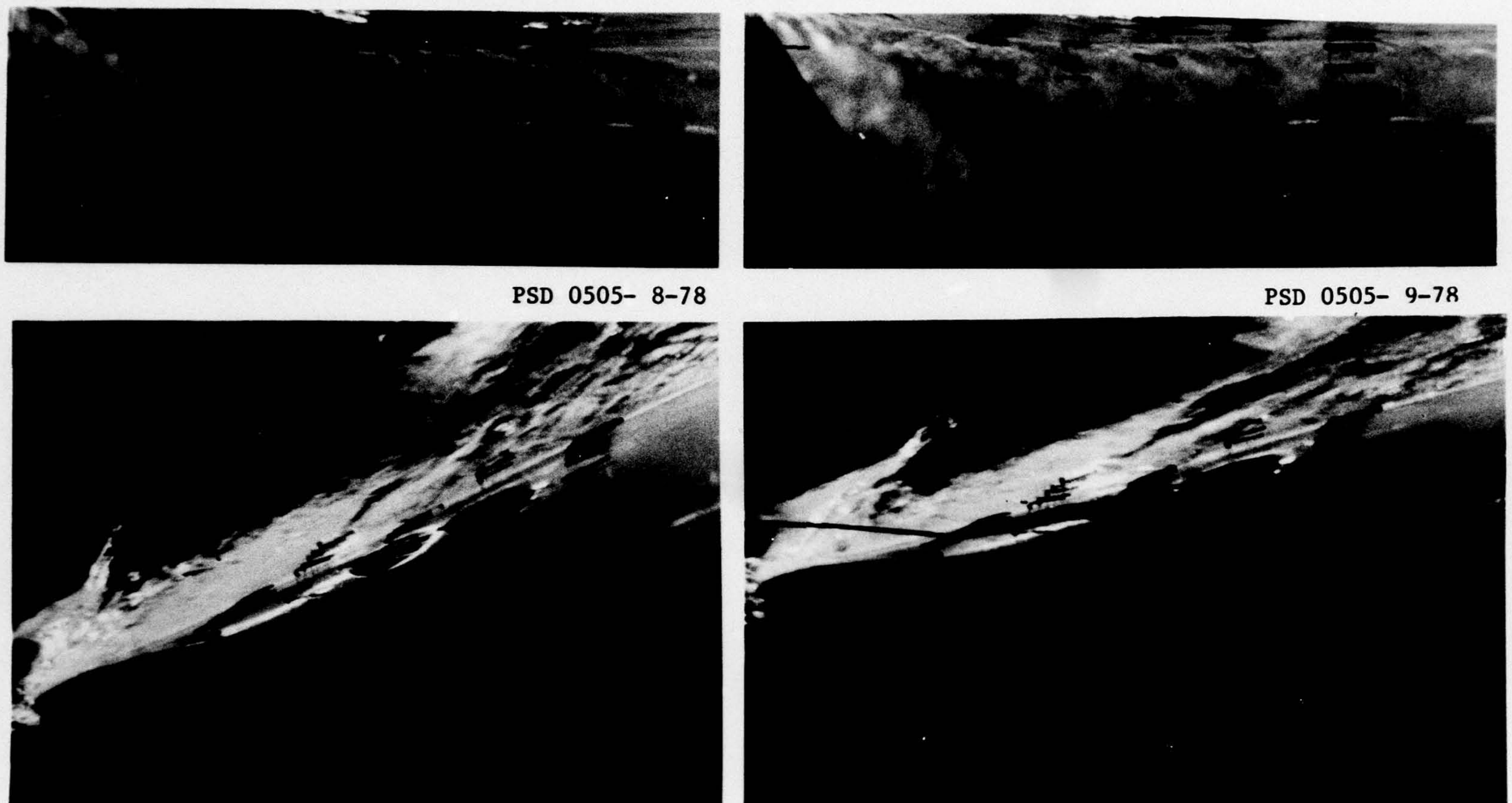
PSD 0506-24-78

PSD 0504-33-78

PSD 0506-23-78

FIGURE 31. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

YAW = 5^{o} PORT. SHIP SPEED = 8 KNOTS.



PSD 0505- 8-78

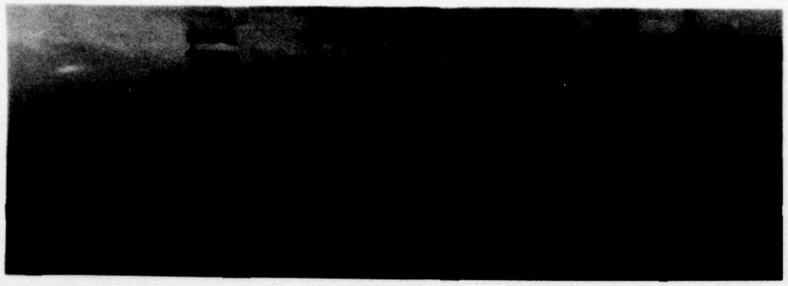
PSD 0505- 9-78

PSD 0505- 7-78

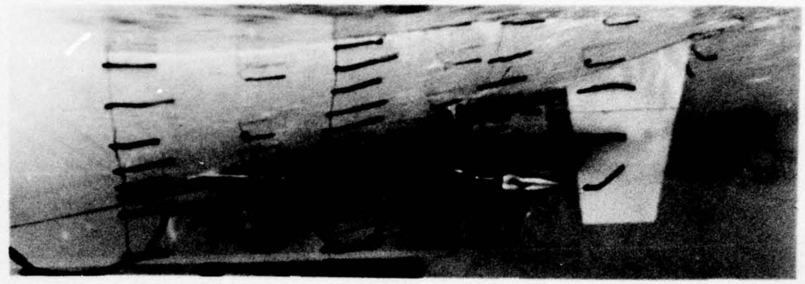
PSD 0505-12-78

FIGURE 32. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL

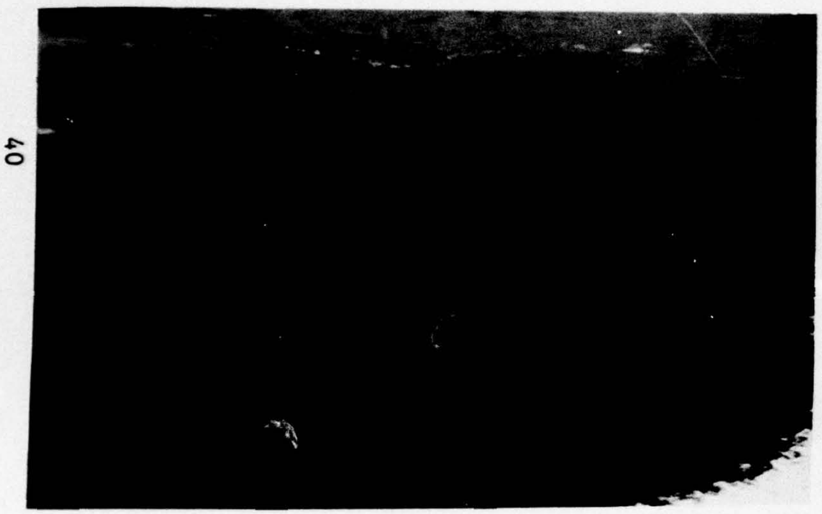
YAW = 5^{o} PORT. SHIP SPEED = 15 KNOTS.



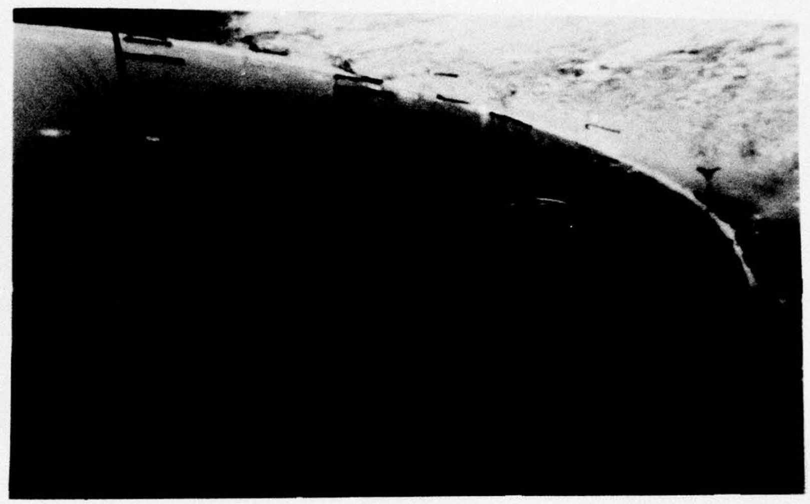
PSD 0505- 5-78



PSD 0506-27-78



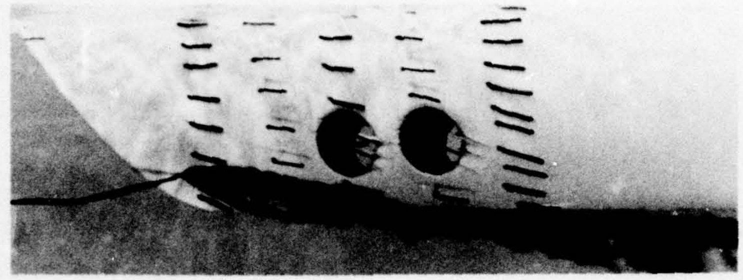
PSD 0505- 6-78



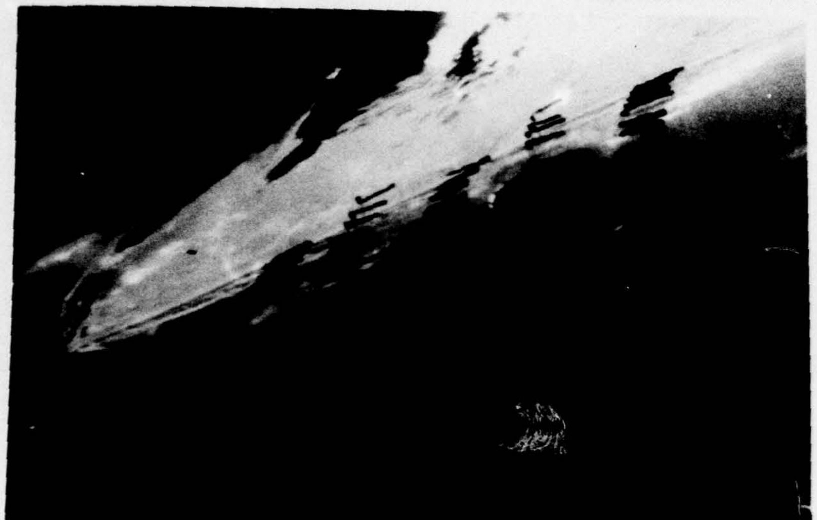
PSD 0506-29-78

FIGURE 33. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.
YAW = 5^{o} PORT. SHIP SPEED = 15 KNOTS

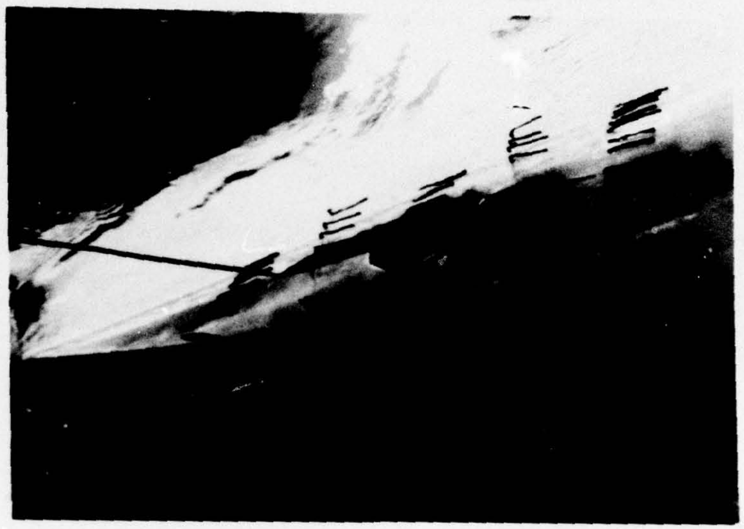
PSD 0504-17-78



PSD 0504-20-78



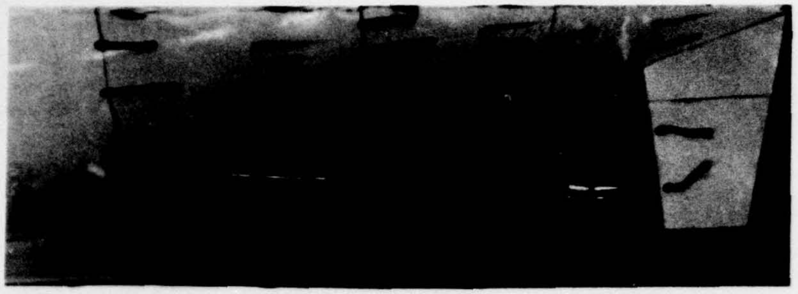
PSD 0504-19-78



PSD 0504-23-78

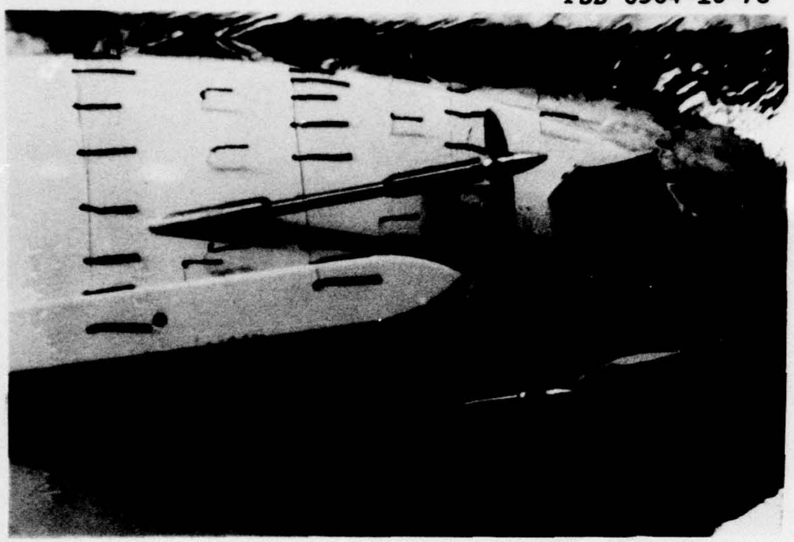
FIGURE 34. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

YAW = 5^{o} STARBOARD. SHIP SPEED = 8 KNOTS



PSD 0504-16-78

PSD 0507- 2-78

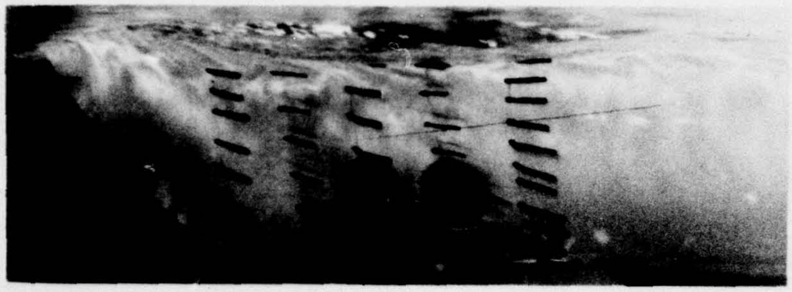


PSD 0504-18-78

PSD 0507- 3-78

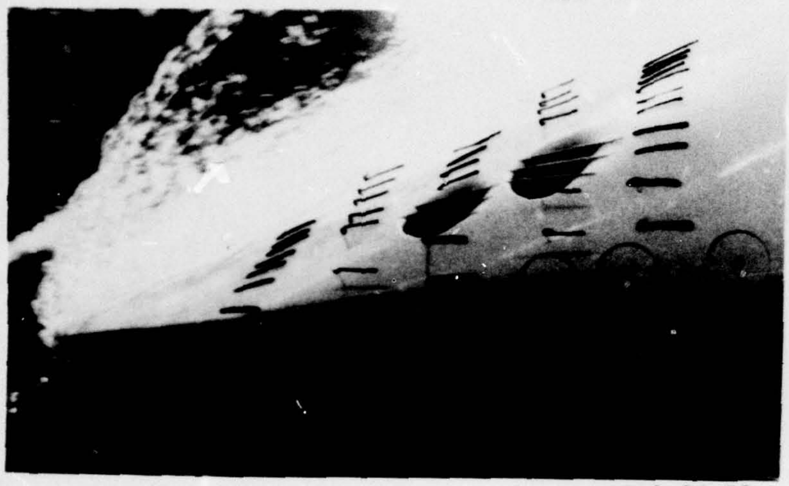
FIGURE 35. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

YAW = 5^{O}STARBOARD. SHIP SPEED = 8 KNOTS

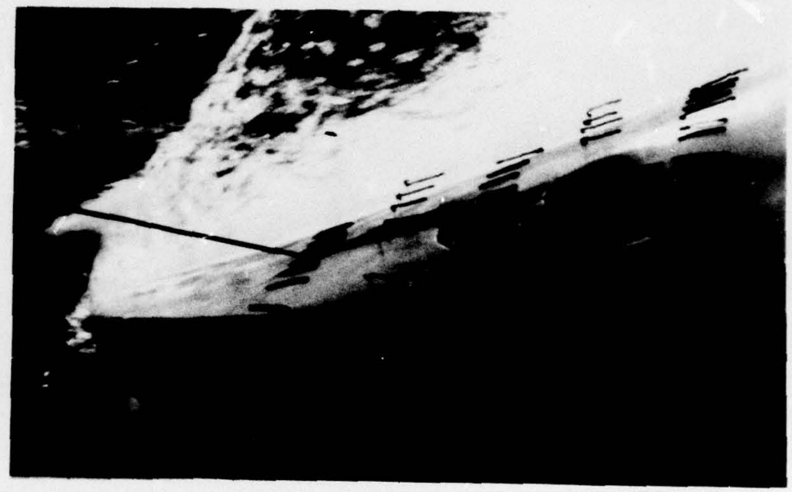


PSD 0504-27-78

PSD 0504-28-78



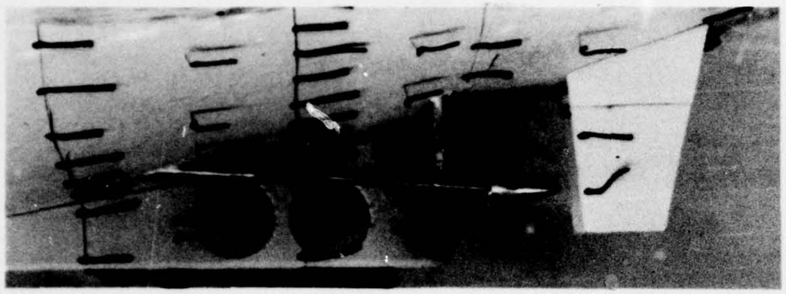
PSD 0504-26-78



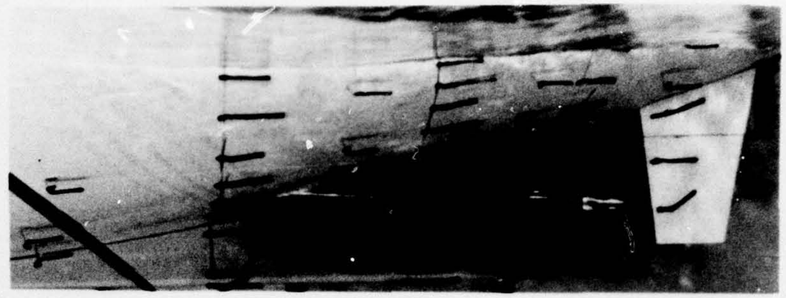
PSD 0504-31-78

FIGURE 36. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

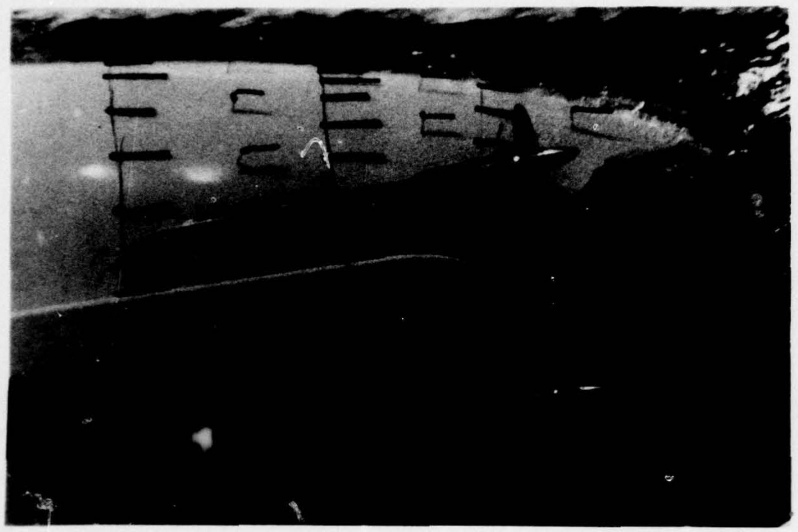
YAW = 5^{o} STARBOARD. SHIP SPEED = 15 KNOTS



PSD 0504-24-78



PSD 0507- 6-78

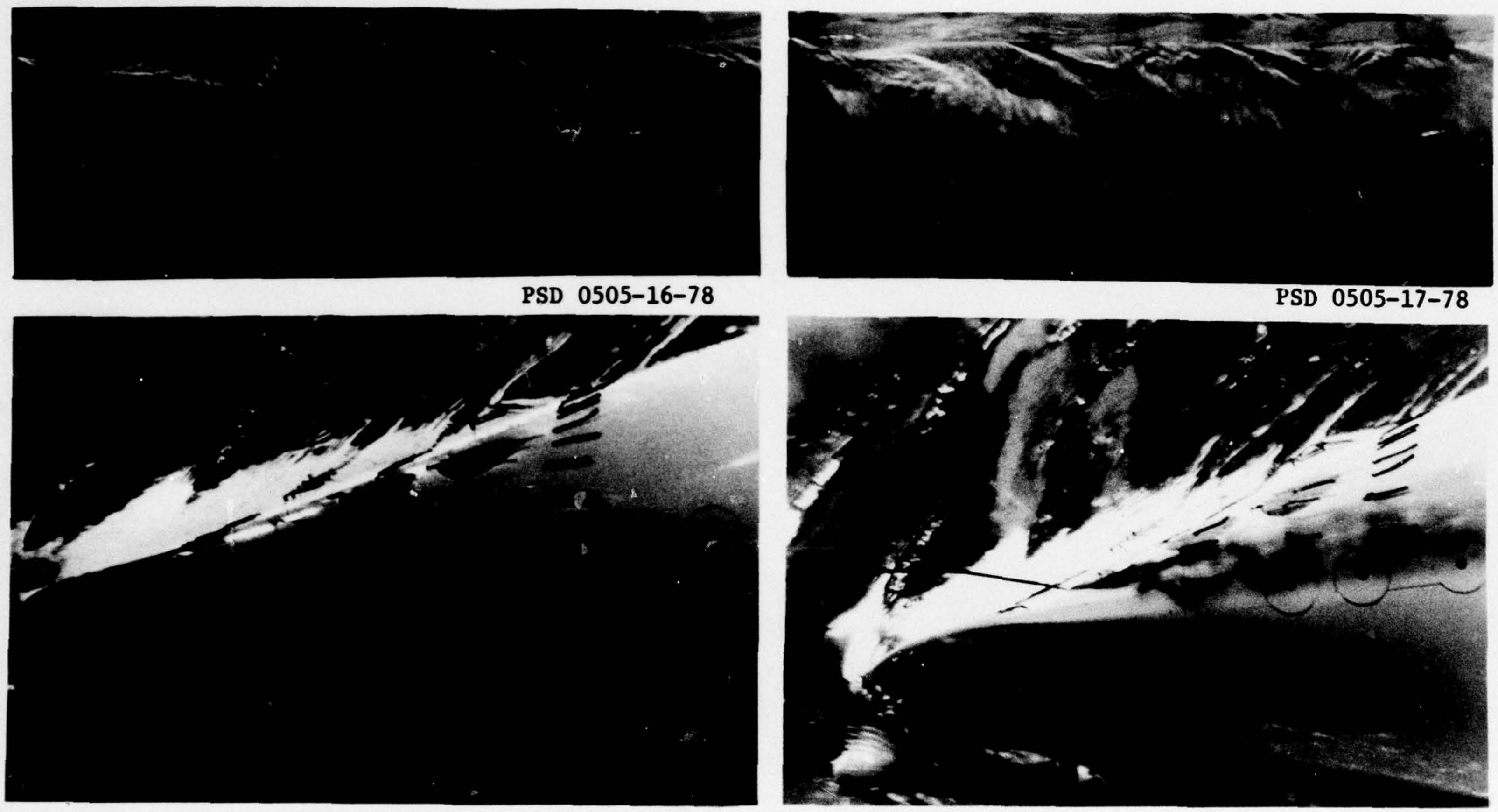


PSD 0504-25-78

PSD 0507- 7-78

FIGURE 37. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL

YAW = 5° STARBOARD. SHIP SPEED = 15 KNOTS



PSD 0505-16-78

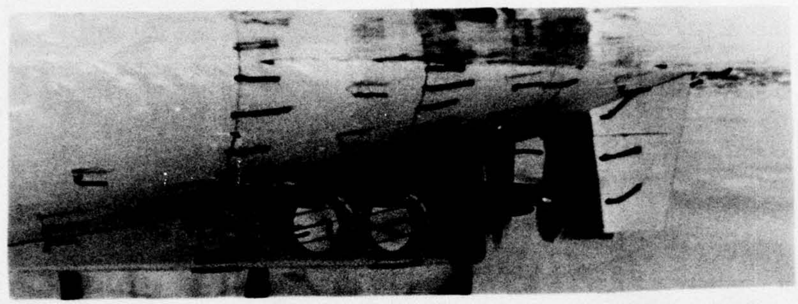
PSD 0505-17-78

PSD 0505-15-78

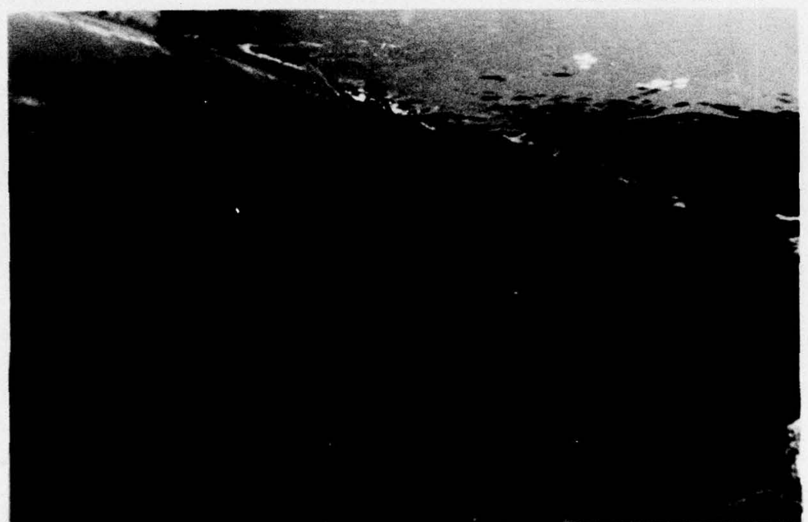
PSD 0505-19-78

FIGURE 38. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

YAW = 10^{o} PORT. SHIP SPEED = 8 KNOTS



PSD 0505-13-78



PSD 0505-14-78

FIGURE 39. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.
YAW = 10^{o} PORT. SHIP SPEED = 8 KNOTS

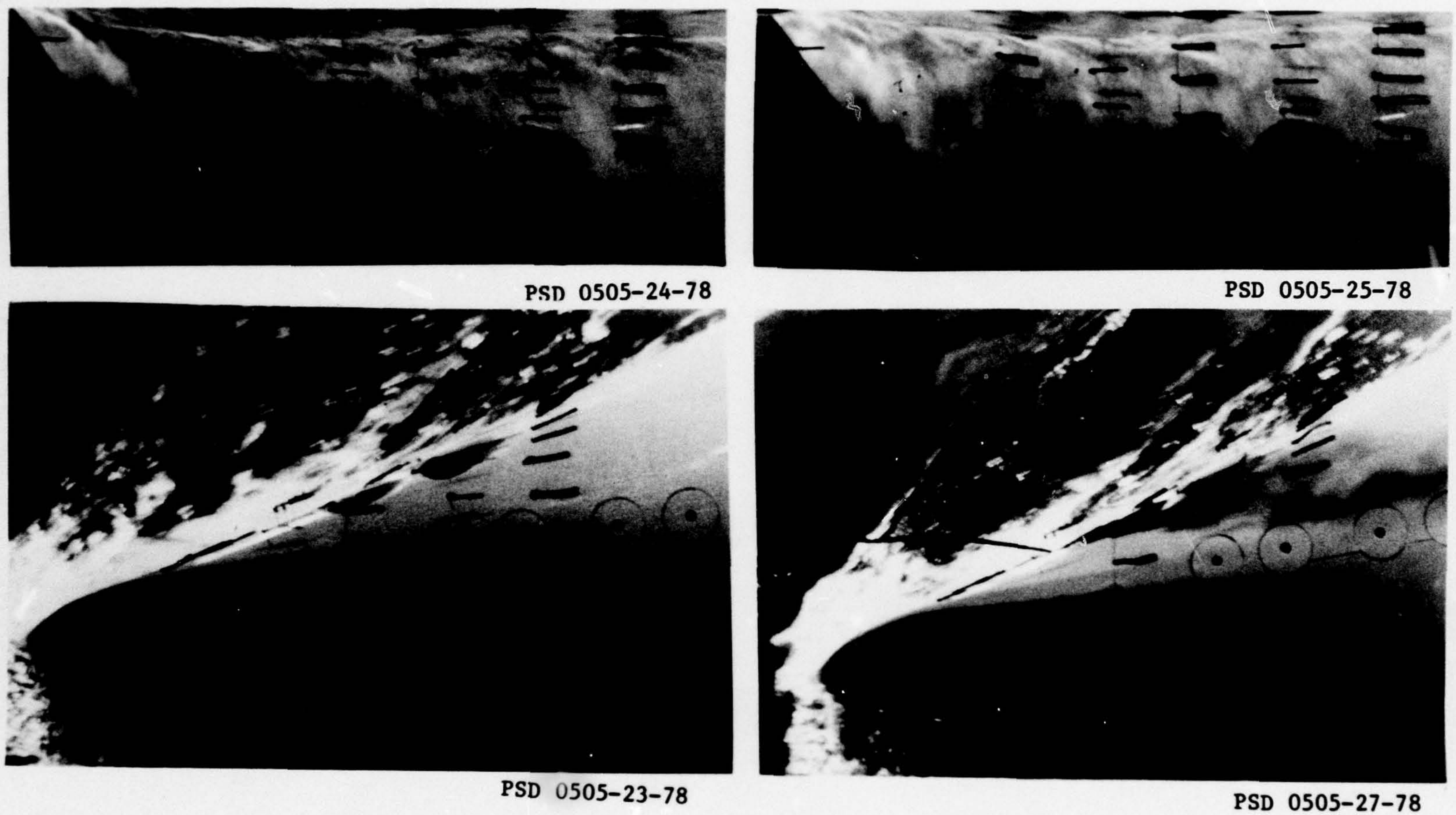


FIGURE 40. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

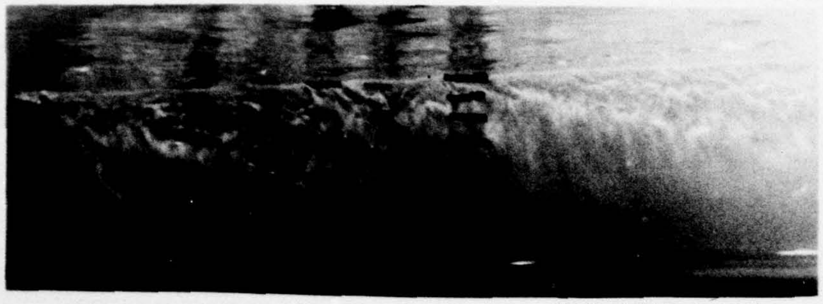
YAW = 10^{o} PORT. SHIP SPEED = 15 KNOTS

PSD 0505-21-78

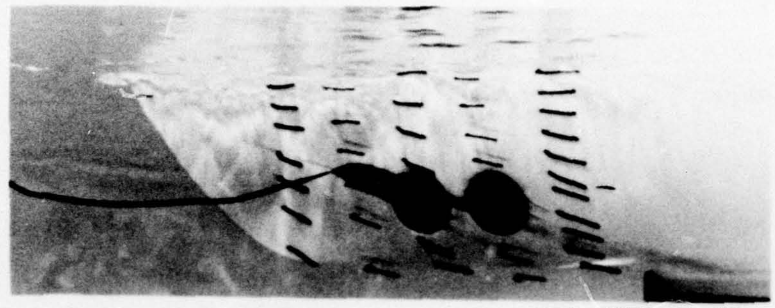
PSD 0505-22-78

FIGURE 41. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

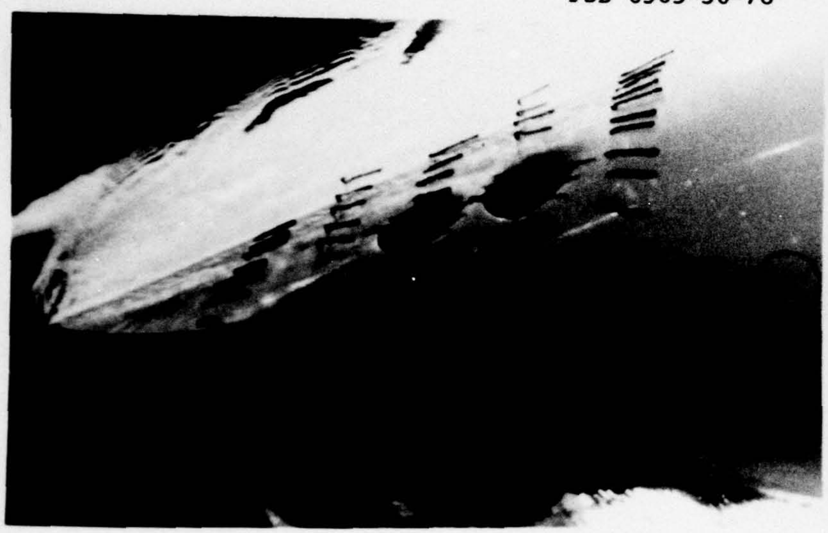
YAW = 10^{o}PORT. SHIP SPEED = 15 KNOTS



PSD 0505-36-78



PSD 0506- 1-78

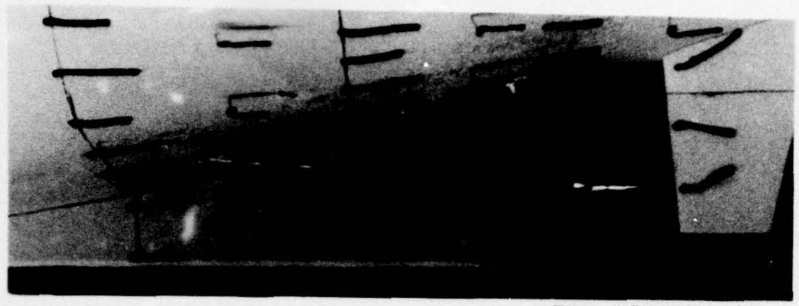


PSD 0505-35-78

PSD 0506- 3-78

FIGURE 42. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

YAW = 10^{o} STARBOARD. SHIP SPEED = 8 KNOTS.



PSD 0505-33-78

PSD 0505-34-78

FIGURE 43. T-ARC, MODEL 5364 IN CIRCULATING WATER CHANNEL.

YAW = 10^{o} STARBOARD. SHIP SPEED = 8 KNOTS

TABLE 1 SHIP AND MODEL DATA FOR T-ARC, MODEL 5364 - BARE HULL.

DESCRIPTION	ENG.	METRIC	SHIP ENG.	SHIP METRIC	MODEL ENG.	MODEL METRIC		
WL LENGTH (LWL)	FT	M	454.0	138.4	19.29	5.88	LINEAR RATIO =	23.537
LENGTH BP (LPP)	FT	M	428.0	130.5	18.18	5.54	V/SQRT(LWL) =	.939
BEAM AT AX (BX)	FT	M	73.0	22.3	3.10	.95	FROUDE NO. =	.279
DRAFT AT AX (TX)	FT	M	24.0	7.3	1.02	.31	CIRCLE K =	2.375
DISPLACEMENT(DIS)	TON	TONNE	14060SW	1428 6SW	1.05FW	1.07FW	XFB/LWL =	.513
	LBS				2348.8		XFB/LPP =	.544
WETTED SURF.(S)	SQ FT	M SQ	38[illegible]7	3538.3	68.75	6.39	XFF/LWL =	.541
DESIGN SPEED(V)	KTS	M/S	[illegible].0	10.3	4.12	2.12	1/2 ENT.ANGLE=	17.0 DEG
							1/2 ENT.ANGLE=	.297RAD

LWL COEFFICIENTS / LPP COEFFICIENTS

LWL				LPP
CB = .618	CPF = .63	LE/L = .45	D-L = 150.26	CB = .656
CP = .695	CPR = .68	LP/L = .12	CVOL= 5.26E-3	CP = .737
CX = .890	CVP = .76	LR/L = .42	CWS = 15.07	L/BX = 5.86
CWP = .816	CVPA = .74	L/BX = 6.22	CS = 2.55	D-L =179.34
CPF = .67	CVPF = .81	BX/TX = 3.04	FTE = 0.00	CVOL = 6.27E-3
CPA = .72	CWF = .73		TTE = .58	
	CWA = .90			

****

FWD STATIONS

STATION	0.00	.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
A/AX	0.000	.039	.116	.204	.292	.472	.643	.786	.891	.959	.991	1.000	1.000
B/BX	.013	.107	.202	.298	.395	.584	.752	.873	.951	.989	1.000	1.000	1.000

****

AFT STATIONS

STATION	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	18.50	19.00	19.50	20.00
A/AX	1.000	.998	.987	.956	.888	.769	.594	.377	.265	.161	.069	0.000
B/BX	1.000	1.000	1.000	1.000	.999	.990	.951	.846	.757	.643	.484	.027

TABLE 2 SHIP AND MODEL DATA FOR T-ARC, MODEL 5364 - BARE HULL AND SKEG.

DESCRIPTION	ENG.	METRIC	SHIP ENG.	SHIP METRIC	MODEL ENG.	MODEL METRIC		
WL LENGTH (LWL)	FT	M	454.0	138.4	19.29	5.88	LINEAR RATIO =	23.537
LENGTH BP (LPP)	FT	M	428.0	130.5	18.18	5.54	V/SQRT(LWL) =	.939
BEAM AT AX (BX)	FT	M	73.0	22.3	3.10	.95	FROUDE NO. =	.279
DRAFT AT AX (TX)	FT	M	24.0	7.3	1.02	.31	CIRCLE K =	2.371
DISPLACEMENT(DIS)	TON	TONNE	14173SW	14401SW	1.06FW	1.07FW	XFB/LWL =	.516
	LBS				2367.7		XFB/LPP =	.547
WETTED SURF.(S)	SQ FT	M SQ	39238.9	3645.4	70.83	6.58	XFF/LWL =	.541
DESIGN SPEED(V)	KTS	M/S	20.0	10.3	4.12	2.12	1/2 ENT.ANGLE=	17.0 DEG
							1/2 ENT.ANGLE=	.297RAD

LWL COEFFICIENTS				LPP COEFFICIENTS
CB = .623	CPE = .63	LE/L = .45	D-L = 151.47	CB = .661
CP = .700	CPR = .69	LP/L = .12	CVOL= 5.30E-3	CP = .743
CX = .890	CVP = .76	LR/L = .42	CWS = 15.47	L/BX = 5.86
CWP = .816	CVPA = .72	L/BX = 6.22	CS = 2.62	D-L =180.78
CPF = .67	CVPF = .81	BX/TX = 3.04	FTE = 0.00	CVOL = 6.32E-3
CPA = .74	CWF = .73		TTE = .58	
	CWA = .90			

****

FWD STATIONS

0.00	.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
A/AX												
0.000	.039	.116	.204	.292	.472	.643	.786	.891	.959	.991	1.000	1.000
B/BX												
.013	.107	.202	.298	.395	.584	.752	.873	.951	.989	1.000	1.000	1.000

****

AFT STATIONS

11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	18.50	19.00	19.50	20.00
A/AX											
1.000	.998	.987	.956	.890	.782	.625	.430	.317	.161	.069	0.000
B/BX											
1.000	1.000	1.000	1.000	.999	.990	.951	.846	.757	.643	.484	.027

TABLE 3 RESISTANCE DATA FOR T-ARC, MODEL 5364 BARE HULL WITH SKEG (SHARP STEM EDGE) EXPERIMENT 1

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO 23.537
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.1	.8	.9	.7	.014	.047	.500
2.00	1.03	8.3	6.2	6.9	5.2	.028	.094	.500
3.00	1.54	26.9	20.1	22.3	16.6	.042	.141	.500
4.00	2.06	62.1	46.3	51.2	38.2	.056	.188	.500
5.00	2.57	119.0	88.7	97.7	72.8	.070	.235	.500
6.00	3.09	202.5	151.0	165.6	123.5	.084	.282	.500
7.00	3.60	315.1	235.0	258.9	193.0	.098	.329	.480
8.00	4.12	462.5	344.9	381.3	284.3	.112	.375	.465
9.00	4.63	664.7	495.7	536.5	400.1	.126	.422	.515
10.00	5.14	931.5	694.6	728.3	543.1	.140	.469	.595
11.00	5.66	1251.3	933.1	960.4	716.2	.154	.516	.640
12.00	6.17	1640.6	1223.4	1236.4	922.0	.168	.563	.685
13.00	6.69	2141.3	1596.8	1560.0	1163.3	.182	.610	.775
14.00	7.20	2773.2	2068.0	1934.7	1442.7	.196	.657	.895
15.00	7.72	3556.7	2652.2	2364.0	1762.9	.209	.704	1.035
16.00	8.23	4571.8	3409.2	2851.7	2126.5	.223	.751	1.230
17.00	8.75	5850.2	4362.5	3401.1	2536.2	.237	.798	1.460
18.00	9.26	7291.5	5437.2	4015.9	2994.6	.251	.845	1.645
19.00	9.77	8891.4	6630.3	4699.5	3504.4	.265	.892	1.790
20.00	10.29	12120.1	9038.0	5455.3	4068.1	.279	.939	2.440

TABLE 4 RESISTANCE DATA FOR T-ARC, MODEL 5364 WITH THRUSTER OPENINGS 1, 2, 3 and 4 OPENED EXPERIMENT 2

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO 23.537
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.4	1.0	.9	.7	.014	.047	1.240
2.00	1.03	10.3	7.7	6.9	5.2	.028	.094	1.240
3.00	1.54	33.7	25.1	22.3	16.6	.042	.141	1.240
4.00	2.06	78.3	58.4	51.2	38.2	.056	.188	1.240
5.00	2.57	150.6	112.3	97.7	72.8	.070	.235	1.240
6.00	3.09	257.1	191.7	165.6	123.5	.084	.282	1.240
7.00	3.60	405.9	302.6	258.9	193.0	.098	.329	1.255
8.00	4.12	608.5	453.8	381.3	284.3	.112	.375	1.300
9.00	4.63	880.0	656.2	536.5	400.1	.126	.422	1.380
10.00	5.14	1216.6	907.2	728.3	543.1	.140	.469	1.430
11.00	5.66	1635.3	1219.4	960.4	716.2	.154	.516	1.485
12.00	6.17	2139.1	1595.2	1236.4	922.0	.168	.563	1.530
13.00	6.69	2786.4	2077.9	1560.0	1163.3	.182	.610	1.635
14.00	7.20	3569.5	2661.8	1934.7	1442.7	.196	.657	1.745
15.00	7.72	4657.2	3472.9	2364.0	1762.9	.209	.704	1.990
16.00	8.23	6061.3	4519.9	2851.7	2126.5	.223	.751	2.295
17.00	8.75	7435.4	5544.6	3401.1	2536.2	.237	.798	2.405
18.00	9.26	9013.9	6721.6	4015.9	2994.6	.251	.845	2.510
19.00	9.77	11081.1	8263.2	4699.5	3504.4	.265	.892	2.725
20.00	10.29	14455.5	10779.5	5455.3	4068.1	.279	.939	3.295

TABLE 5 RESISTANCE DATA FOR T-ARC, MODEL 5364 BARE HULL WITH SKEG (ROUNDED STEM EDGE) EXPERIMENT 3

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO 23.537
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.1	.8	.9	.7	.014	.047	.500
2.00	1.03	8.3	6.2	6.9	5.2	.028	.094	.500
3.00	1.54	26.9	20.1	22.3	16.6	.042	.141	.500
4.00	2.06	62.1	46.3	51.2	38.2	.056	.188	.500
5.00	2.57	119.0	88.7	97.7	72.8	.070	.235	.500
6.00	3.09	202.5	151.0	165.6	123.5	.084	.282	.500
7.00	3.60	315.1	235.0	258.9	193.0	.098	.329	.480
8.00	4.12	462.5	344.9	381.3	284.3	.112	.375	.465
9.00	4.63	664.7	495.7	536.5	400.1	.126	.422	.515
10.00	5.14	931.5	694.6	728.3	543.1	.140	.469	.595
11.00	5.66	1251.3	933.1	960.4	716.2	.154	.516	.640
12.00	6.17	1640.6	1223.4	1236.4	922.0	.168	.563	.685
13.00	6.69	2141.3	1596.8	1560.0	1163.3	.182	.610	.775
14.00	7.20	2773.2	2068.0	1934.7	1442.7	.196	.657	.895
15.00	7.72	3556.7	2652.2	2364.0	1762.9	.209	.704	1.035
16.00	8.23	4571.8	3409.2	2851.7	2126.5	.223	.751	1.230
17.00	8.75	5850.2	4362.5	3401.1	2536.2	.237	.798	1.460
18.00	9.26	7291.5	5437.2	4015.9	2994.6	.251	.845	1.645
19.00	9.77	8891.4	6630.3	4699.5	3504.4	.265	.892	1.790
20.00	10.29	12120.1	9038.0	5455.3	4068.1	.279	.939	2.440

TABLE 6 RESISTANCE DATA FOR T-ARC, MODEL 5364 THRUSTER OPENING 1 WITH GRATING EXPERIMENT 4

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO	23.537
ITTC FRICTION LINE	
CORRELATION ALLOWANCE (CA)	.00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.2	.9	.9	.7	.014	.047	.675
2.00	1.03	8.8	6.5	6.9	5.2	.028	.094	.675
3.00	1.54	28.5	21.3	22.3	16.6	.042	.141	.675
4.00	2.06	66.0	49.2	51.2	38.2	.056	.188	.675
5.00	2.57	126.5	94.3	97.7	72.8	.070	.235	.675
6.00	3.09	215.4	160.6	165.5	123.5	.084	.282	.675
7.00	3.60	336.2	250.7	258.9	193.0	.098	.329	.660
8.00	4.12	490.5	365.8	381.3	284.3	.112	.375	.625
9.00	4.63	693.3	517.0	536.5	400.1	.126	.422	.630
10.00	5.14	963.9	718.8	728.3	543.1	.140	.469	.690
11.00	5.66	1324.0	987.3	960.4	716.2	.154	.516	.800
12.00	6.17	1729.1	1289.4	1236.4	922.0	.168	.563	.835
13.00	6.69	2220.1	1655.5	1560.0	1163.3	.182	.610	.880
14.00	7.20	2834.1	2113.4	1934.7	1442.7	.196	.657	.960
15.00	7.72	3631.6	2708.1	2364.0	1762.9	.209	.704	1.100
16.00	8.23	4669.7	3482.2	2851.7	2126.5	.223	.751	1.300
17.00	8.75	5959.2	4443.8	3401.1	2536.2	.237	.798	1.525
18.00	9.26	7291.5	5437.2	4015.9	2994.6	.251	.845	1.645
19.00	9.77	9113.9	6796.2	4699.5	3504.4	.265	.892	1.885
20.00	10.29	12884.9	9608.3	5455.3	4068.1	.279	.939	2.720

TABLE 7 RESISTANCE DATA FOR T-ARC, MODEL 5364 THRUSTER OPENING 1 WITHOUT GRATING EXPERIMENT 5

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244. SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301. TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO 23.537
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.3	.9	.9	.7	.014	.047	.950
2.00	1.03	9.5	7.1	6.9	5.2	.028	.094	.950
3.00	1.54	31.0	23.2	22.3	16.6	.042	.141	.950
4.00	2.06	72.0	53.7	51.2	38.2	.056	.188	.950
5.00	2.57	138.2	103.1	97.7	72.8	.070	.235	.950
6.00	3.09	235.7	175.7	165.6	123.5	.084	.282	.950
7.00	3.60	370.1	276.0	258.9	193.0	.098	.329	.950
8.00	4.12	549.1	409.4	381.3	284.3	.112	.375	.960
9.00	4.63	780.4	582.0	536.5	400.1	.126	.422	.980
10.00	5.14	1073.2	800.3	728.3	543.1	.140	.469	1.010
11.00	5.66	1446.7	1078.8	960.4	716.2	.154	.516	1.070
12.00	6.17	1926.7	1436.8	1236.4	922.0	.168	.563	1.170
13.00	6.69	2557.7	1907.2	1560.0	1163.3	.182	.610	1.330
14.00	7.20	3321.3	2476.7	1934.7	1442.7	.196	.657	1.480
15.00	7.72	4296.5	3203.9	2364.0	1762.9	.209	.704	1.677
16.00	8.23	5452.9	4066.2	2851.7	2126.5	.223	.751	1.860
17.00	8.75	6714.1	5006.7	3401.1	2536.2	.237	.798	1.975
18.00	9.26	8277.1	6172.2	4015.9	2994.6	.251	.845	2.140
19.00	9.77	10238.0	7634.5	4699.5	3504.4	.265	.892	2.365
20.00	10.29	12884.9	9608.3	5455.3	4068.1	.279	.939	2.720

TABLE 8 RESISTANCE DATA FOR T-ARC, MODEL 5364 THRUSTER OPENINGS 1 and 2 WITH GRATING EXPERIMENT 6

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO	23.537
ITTC FRICTION LINE	
CORRELATION ALLOWANCE (CA)	.00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.2	.9	.9	.7	.014	.047	.770
2.00	1.03	9.0	6.7	6.9	5.2	.028	.094	.770
3.00	1.54	29.4	21.9	22.3	16.6	.042	.141	.770
4.00	2.06	68.0	50.7	51.2	38.2	.056	.188	.770
5.00	2.57	130.5	97.3	97.7	72.8	.070	.235	.770
6.00	3.09	222.4	165.8	165.6	123.5	.084	.282	.770
7.00	3.60	347.3	259.0	258.9	193.0	.098	.329	.755
8.00	4.12	516.7	385.3	381.3	284.3	.112	.375	.775
9.00	4.63	733.1	546.7	536.5	400.1	.126	.422	.730
10.00	5.14	1023.7	763.4	728.3	543.1	.140	.469	.865
11.00	5.66	1369.4	1021.2	960.4	716.2	.154	.516	.900
12.00	6.17	1776.3	1324.6	1236.4	922.0	.168	.563	.915
13.00	6.69	2280.1	1700.3	1560.0	1163.3	.182	.610	.960
14.00	7.20	2941.8	2193.7	1934.7	1442.7	.196	.657	1.075
15.00	7.72	3798.7	2832.7	2364.0	1762.9	.209	.704	1.245
16.00	8.23	4886.5	3643.9	2851.7	2126.5	.223	.751	1.455
17.00	8.75	6143.8	4581.4	3401.1	2536.2	.237	.798	1.635
18.00	9.26	7540.4	5622.8	4015.9	2994.6	.251	.845	1.770
19.00	9.77	9359.8	6979.6	4699.5	3504.4	.265	.892	1.990
20.00	10.29	13349.3	9954.6	5[illegible]5.3	4068.1	.279	.939	2.890

TABLE 9 RESISTANCE DATA FOR T-ARC, MODEL 5364 THRUSTER OPENINGS 1, 2, and 3 WITH GRATING EXPERIMENT 7

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO 23.537
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.3	.9	.9	.7	.014	.047	.940
2.00	1.03	9.5	7.1	6.9	5.2	.028	.094	.940
3.00	1.54	31.0	23.1	22.3	16.6	.042	.141	.940
4.00	2.06	71.7	53.5	51.2	38.2	.056	.188	.940
5.00	2.57	137.8	102.8	97.7	72.8	.070	.235	.940
6.00	3.09	234.9	175.2	165.6	123.5	.084	.282	.940
7.00	3.60	366.6	273.4	258.9	193.0	.098	.329	.920
8.00	4.12	542.1	404.2	381.3	284.3	.112	.375	.920
9.00	4.63	771.7	575.5	536.5	400.1	.126	.422	.945
10.00	5.14	1066.4	795.2	728.3	543.1	.140	.469	.930
11.00	5.66	1421.7	1060.2	960.4	716.2	.154	.516	1.015
12.00	6.17	1841.2	1373.0	1236.4	922.0	.168	.563	1.025
13.00	6.69	2373.9	1770.2	1560.0	1163.3	.182	.610	1.085
14.00	7.20	3058.9	2281.0	1934.7	1442.7	.196	.657	1.200
15.00	7.72	3965.8	2957.3	2364.0	1762.9	.209	.704	1.390
16.00	8.23	5082.3	3789.9	2851.7	2126.5	.223	.751	1.595
17.00	8.75	6319.9	4712.7	3401.1	2536.2	.237	.798	1.740
18.00	9.26	8058.1	6008.9	4015.9	2994.6	.251	.845	2.030
19.00	9.77	9746.2	7267.8	4699.5	3504.4	.265	.892	2.155
20.00	10.29	13718.0	10229.5	5455.3	4068.1	.279	.939	3.025

TABLE 10 RESISTANCE DATA FOR T-ARC, MODEL 5364 THRUSTER OPENINGS 1, 2, 3 and 4 WITH GRATING EXPERIMENT 8

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO	23.537
ITTC FRICTION LINE	
CORRELATION ALLOWANCE (CA)	.00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.3	1.0	.9	.7	.014	.047	1.025
2.00	1.03	9.7	7.2	6.9	5.2	.028	.094	1.025
3.00	1.54	31.7	23.7	22.3	16.6	.042	.141	1.025
4.00	2.06	73.6	54.9	51.2	38.2	.056	.188	1.025
5.00	2.57	141.4	105.5	97.7	72.8	.070	.235	1.025
6.00	3.09	241.2	179.9	165.6	123.5	.084	.282	1.025
7.00	3.60	378.3	282.1	258.9	193.0	.098	.329	1.020
8.00	4.12	558.7	416.6	381.3	284.3	.112	.375	1.015
9.00	4.63	790.4	589.4	536.5	400.1	.126	.422	1.020
10.00	5.14	1092.0	814.3	728.3	543.1	.140	.469	1.065
11.00	5.66	1480.8	1104.2	960.4	716.2	.154	.516	1.145
12.00	6.17	1944.4	1450.0	1236.4	922.0	.168	.563	1.200
13.00	6.69	2490.1	1856.9	1560.0	1163.3	.182	.610	1.240
14.00	7.20	3190.1	2378.9	1934.7	1442.7	.196	.657	1.340
15.00	7.72	4086.8	3047.5	2364.0	1762.9	.209	.704	1.495
16.00	8.23	5222.2	3894.2	2851.7	2126.5	.223	.751	1.695
17.00	8.75	6571.5	4900.4	3401.1	2536.2	.237	.798	1.890
18.00	9.26	8297.0	6187.1	4015.9	2994.6	.251	.845	2.150
19.00	9.77	10027.3	7477.3	4699.5	3504.4	.265	.892	2.275
20.00	10.29	13081.9	10351.7	5455.3	4068.1	.279	.939	3.085

TABLE 11 RESISTANCE DATA FOR T-ARC, MODEL 5364 THRUSTER OPENINGS 1, 3, 4 and 5 WITH GRATING EXPERIMENT 9

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO	23.537
ITTC FRICTION LINE	
CORRELATION ALLOWANCE (CA)	.00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.1	.8	.9	.7	.014	.047	.525
2.00	1.03	8.3	6.2	6.9	5.2	.028	.094	.525
3.00	1.54	27.1	20.2	22.3	16.6	.042	.141	.525
4.00	2.06	62.7	46.7	51.2	38.2	.056	.188	.525
5.00	2.57	120.1	89.5	97.7	72.8	.070	.235	.525
6.00	3.09	204.3	152.4	165.6	123.5	.084	.282	.525
7.00	3.60	320.9	239.3	258.9	193.0	.098	.329	.530
8.00	4.12	478.3	356.7	381.3	284.3	.112	.375	.555
9.00	4.63	685.9	511.4	536.5	400.1	.126	.422	.600
10.00	5.14	953.7	711.2	728.3	543.1	.140	.469	.660
11.00	5.66	1292.2	963.6	960.4	716.2	.154	.516	.730
12.00	6.17	1723.2	1285.0	1236.4	922.0	.168	.563	.825
13.00	6.69	2261.4	1686.3	1560.0	1163.3	.182	.610	.935
14.00	7.20	2885.6	2151.8	1934.7	1442.7	.196	.657	1.015
15.00	7.72	3902.4	2910.0	2364.0	1762.9	.209	.704	1.335
16.00	8.23	5082.3	3789.9	2851.7	2126.5	.223	.751	1.595
17.00	8.75	6378.6	4756.5	3401.1	2536.2	.237	.798	1.775
18.00	9.26	7839.0	5845.6	4015.9	2994.6	.251	.845	1.920
19.00	9.77	9886.7	7372.5	4699.5	3504.4	.265	.892	2.215
20.00	10.29	13800.0	10290.6	5455.3	4068.1	.279	.939	3.055

TABLE 12 RESISTANCE DATA FOR T-ARC, MODEL 5364 THRUSTER OPENINGS 3, 4, 5 and 6 WITH GRATING EXPERIMENT 10

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3645. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO 23.537
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.2	.9	.9	.7	.014	.047	.770
2.00	1.03	9.0	6.7	6.9	5.2	.028	.094	.770
3.00	1.54	29.4	21.9	22.3	16.6	.042	.141	.770
4.00	2.06	68.0	50.7	51.2	38.2	.056	.188	.770
5.00	2.57	130.5	97.3	97.7	72.8	.070	.235	.770
6.00	3.09	222.4	165.8	165.6	123.5	.084	.282	.770
7.00	3.60	349.1	260.3	258.9	193.0	.098	.329	.770
8.00	4.12	518.5	386.6	381.3	284.3	.112	.375	.785
9.00	4.63	743.1	554.1	536.5	400.1	.126	.422	.830
10.00	5.14	1030.5	768.5	728.3	543.1	.140	.469	.885
11.00	5.66	1396.7	1041.5	960.4	716.2	.154	.516	.960
12.00	6.17	1838.2	1370.8	1236.4	922.0	.168	.563	1.020
13.00	6.69	2370.1	1767.4	1560.0	1163.3	.182	.610	1.080
14.00	7.20	3058.9	2281.0	1934.7	1442.7	.196	.657	1.200
15.00	7.72	3931.2	2931.5	2364.0	1762.9	.209	.704	1.360
16.00	8.23	5033.4	3753.4	2851.7	2126.5	.223	.751	1.560
17.00	8.75	6252.8	4662.7	3401.1	2536.2	.237	.798	1.700
18.00	9.26	7669.8	5719.4	4015.9	2994.6	.251	.845	1.835
19.00	9.77	9582.3	7145.5	4699.5	3504.4	.265	.892	2.085
20.00	10.29	13595.1	10137.9	5455.3	4068.1	.279	.939	2.980

TABLE 13 RESISTANCE DATA FOR T-ARC, MODEL 5364 THRUSTER OPENING 5 WITH GRATING EXPERIMENT 11

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	39244.SQ FT (3646. SQ M)	70.84 SQ FT (6.58 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO	23.537
ITTC FRICTION LINE	
CORRELATION ALLOWANCE (CA)	.00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.1	.8	.9	.7	.014	.047	.460
2.00	1.03	8.2	6.1	6.9	5.2	.028	.094	.460
3.00	1.54	26.5	19.8	22.3	16.6	.042	.141	.460
4.00	2.06	61.3	45.7	51.2	38.2	.056	.188	.460
5.00	2.57	117.3	87.5	97.7	72.8	.070	.235	.460
6.00	3.09	199.5	148.8	165.6	123.5	.084	.282	.460
7.00	3.60	314.5	234.5	258.9	193.0	.098	.329	.475
8.00	4.12	468.7	349.5	381.3	284.3	.112	.375	.500
9.00	4.63	672.2	501.2	536.5	400.1	.126	.422	.545
10.00	5.14	945.2	704.8	728.3	543.1	.140	.469	.635
11.00	5.66	1294.5	965.3	960.4	716.2	.154	.516	.735
12.00	6.17	1723.2	1285.0	1236.4	922.0	.168	.563	.825
13.00	6.69	2220.1	1655.5	1560.0	1163.3	.182	.610	.880
14.00	7.20	2834.1	2113.4	1934.7	1442.7	.196	.657	.950
15.00	7.72	3631.6	2708.1	2364.0	1762.9	.209	.704	1.100
16.00	8.23	4669.7	3482.2	2851.7	2126.5	.223	.751	1.300
17.00	8.75	5959.2	4443.8	3401.1	2536.2	.237	.798	1.525
18.00	9.26	7401.0	5518.9	4015.9	2994.6	.251	.845	1.700
19.00	9.77	9254.4	6901.0	4699.5	3504.4	.265	.892	1.945
20.00	10.29	12884.9	9608.3	5455.3	4068.1	.279	.939	2.720

TABLE 14 RESISTANCE DATA FOR T-ARC, MODEL 5364 BARE HULL (WITHOUT SKEG) EXPERIMENT 12

	SHIP	MODEL
LENGTH	454.00 FT (138.4 M)	19.29 FT (5.879 M)
WETTED SURFACE	38086.SQ FT (3538. SQ M)	68.75 SQ FT (6.39 SQ M)
DISPLACEMENT	14301.TONS (14531. TONNE)	1.07 TONS (1.08 TONNE)

LINEAR RATIO 23.537
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
1.00	.51	1.0	.8	.9	.7	.014	.047	.290
2.00	1.03	7.5	5.6	6.7	5.0	.028	.094	.290
3.00	1.54	24.2	18.1	21.6	16.1	.042	.141	.290
4.00	2.06	55.8	41.6	49.7	37.1	.056	.188	.290
5.00	2.57	106.8	79.6	94.8	70.7	.070	.235	.290
6.00	3.09	181.5	135.3	160.7	119.9	.084	.282	.290
7.00	3.60	280.2	209.0	251.2	187.3	.098	.329	.255
8.00	4.12	410.7	306.3	370.0	275.9	.112	.375	.240
9.00	4.63	591.9	441.4	520.7	388.3	.126	.422	.295
10.00	5.14	839.4	625.9	706.9	527.1	.140	.469	.400
11.00	5.66	1143.8	852.9	932.1	695.1	.154	.516	.480
12.00	6.17	1489.1	1110.4	1200.0	894.8	.168	.563	.505
13.00	6.69	1921.6	1433.0	1514.0	1129.0	.182	.610	.560
14.00	7.20	2459.5	1834.1	1877.6	1400.1	.196	.657	.640
15.00	7.72	3166.6	2361.3	2294.3	1710.9	.209	.704	.780
16.00	8.23	4070.5	3035.4	2767.5	2063.8	.223	.751	.950
17.00	8.75	5238.1	3906.0	3300.8	2461.4	.237	.798	1.190
18.00	9.26	6602.9	4923.8	3897.4	2906.3	.251	.845	1.400
19.00	9.77	8254.1	6155.1	4560.8	3401.0	.265	.892	1.625
20.00	10.29	11219.1	8366.1	5294.4	3948.0	.279	.939	2.235

TABLE 15 THE EFFECT OF THRUSTER OPENINGS ON RESISTANCE

EXPT. NO.	Model Conditions	EHP / EHP EXPT. 12 8 knots	15 knots
1	Bare hull with skeg, sharp stem edge	1.122	1.119
2	Thruster openings 1, 2, 3 and 4 open sharp stem edge	1.476	1.465
3	Bare hull with skeg, rounded stem edge	1.112	1.119
4	Thruster opening 1 with gratings	1.190	1.142
5	Thruster opening 1 without gratings	1.332	1.357
6	Thruster openings 1 and 2 with gratings	1.253	1.195
7	Thruster openings 1, 2, and 3 with gratings	1.315	1.248
8	Thruster openings 1, 2, 3, and 4 with gratings	1.355	1.286
9	Thruster openings 1, 3, 4, and 5 with gratings	1.160	1.228
10	Thruster openings 3, 4, 5 and 6 with gratings	1.223	1.237
11	Thruster opening 5 with gratings	1.137	1.142
12	Bare hull without skeg	1.000	1.000

APPENDIX

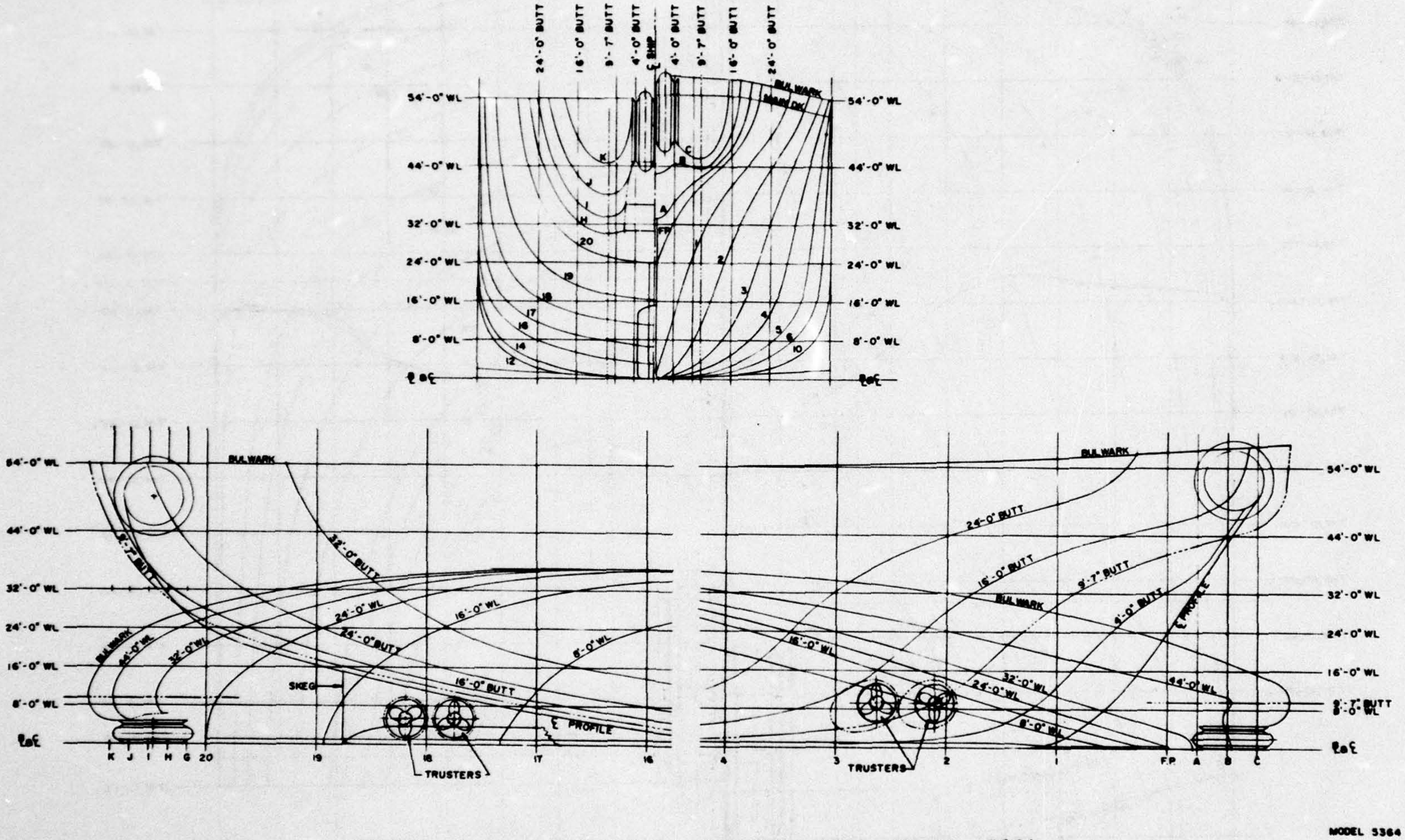


FIGURE 1a. ABBREVIATED LINES OF T-ARC, MODEL 5364.

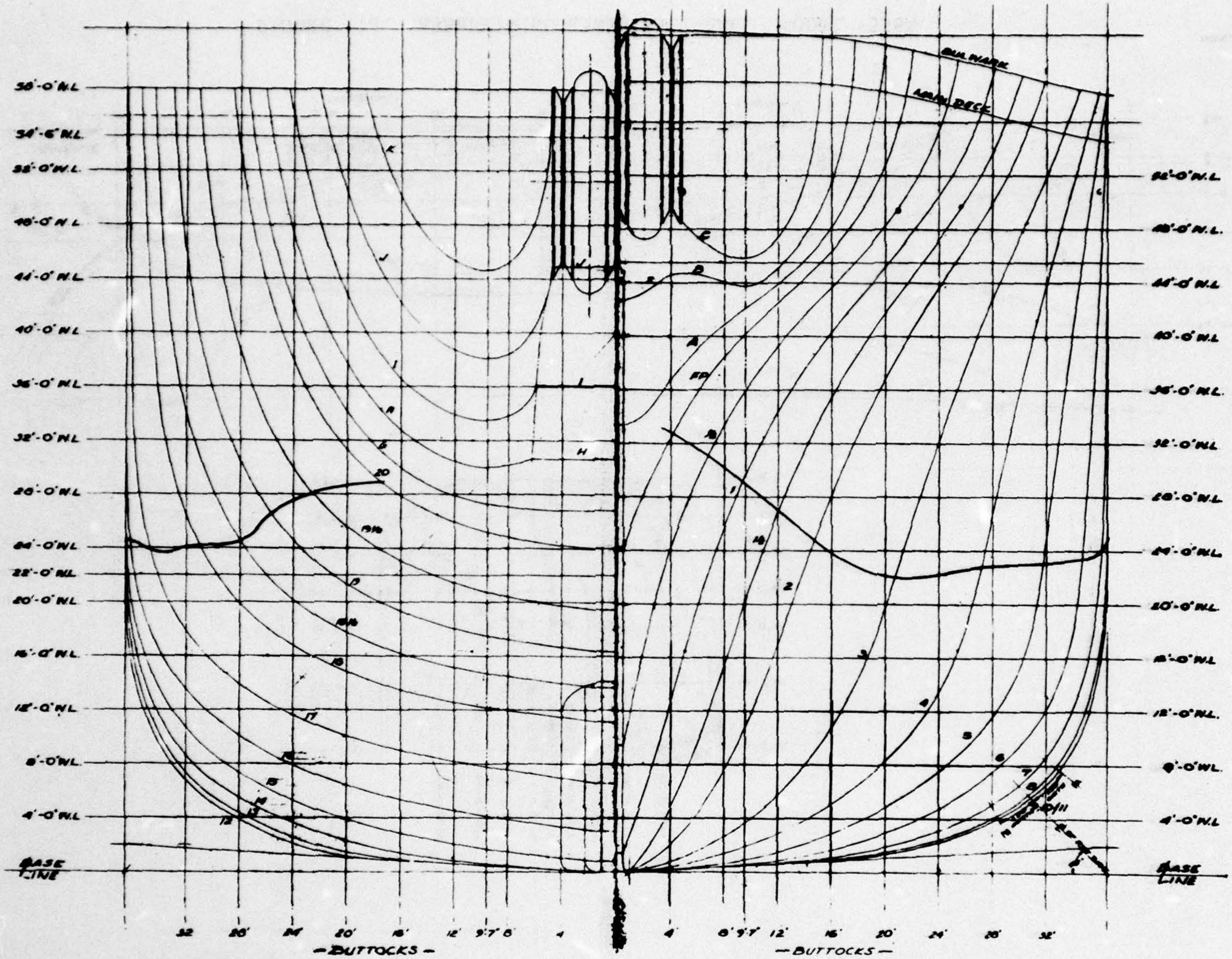


FIGURE 2a. WAVE PROFILE TRACE OF T-ARC, MODEL 5364, AT 15 KNOTS SHIP SPEED.

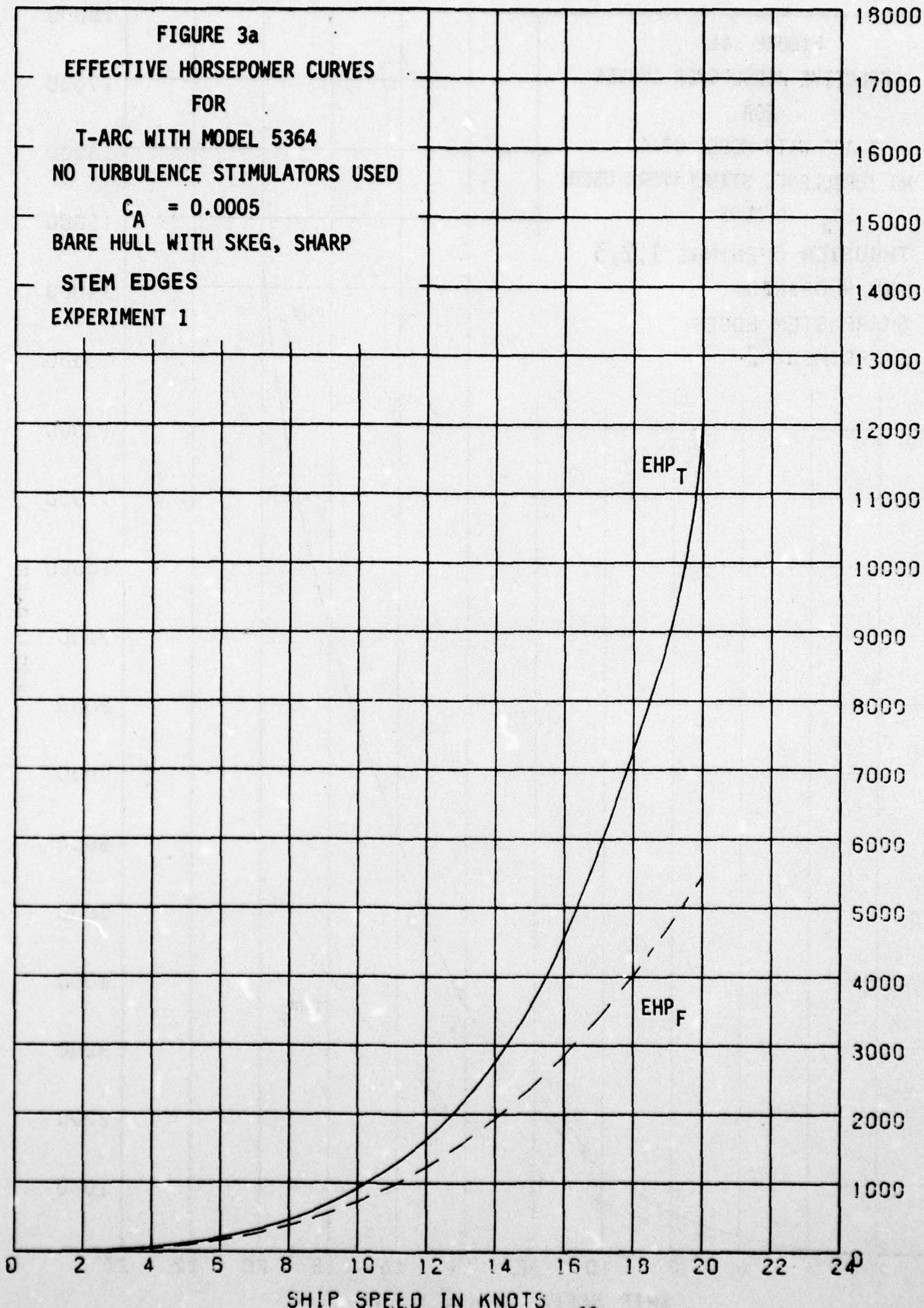


FIGURE 3a
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
BARE HULL WITH SKEG, SHARP
STEM EDGES
EXPERIMENT 1
EHP$_T$
EHP$_F$
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
HORSEPOWER
0
2
4
6
8
10
12
14
16
18
20
22
24
SHIP SPEED IN KNOTS

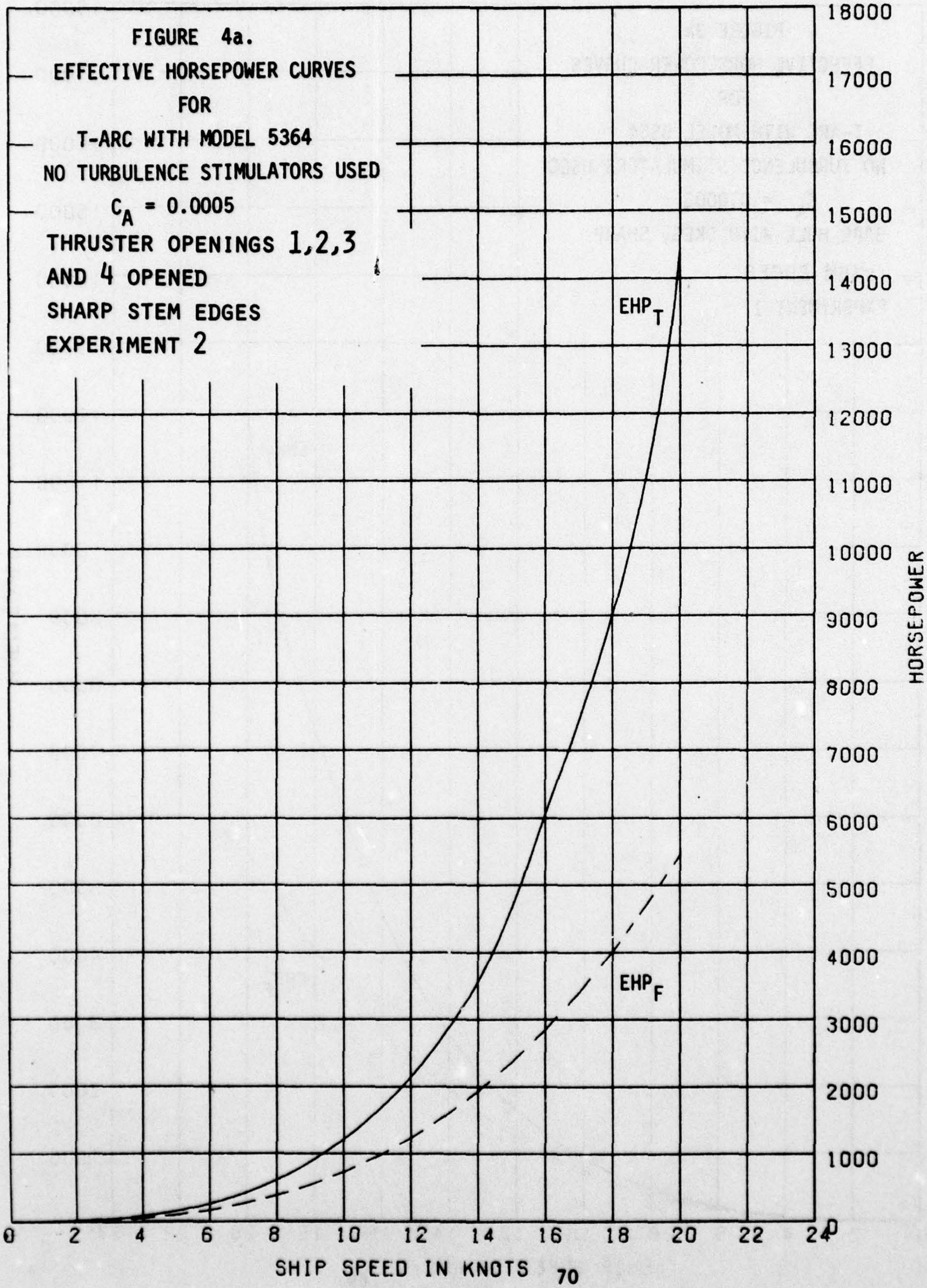


FIGURE 4a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENINGS 1,2,3
AND 4 OPENED
SHARP STEM EDGES
EXPERIMENT 2
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
HORSEPOWER
0
2
4
6
8
10
12
14
16
18
20
22
24
SHIP SPEED IN KNOTS

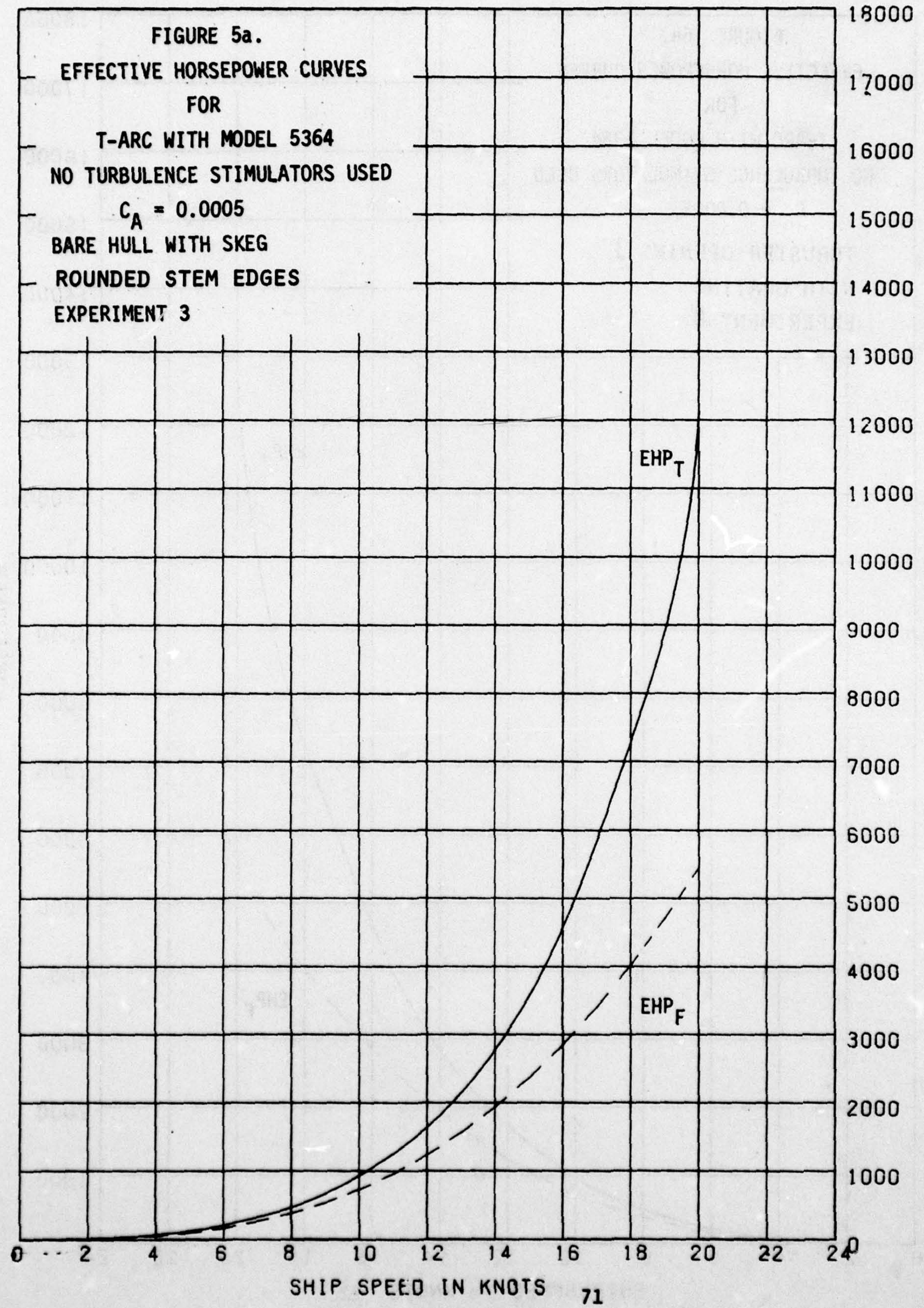


FIGURE 5a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
BARE HULL WITH SKEG
ROUNDED STEM EDGES
EXPERIMENT 3
EHP_T
EHP_F
0 2 4 6 8 10 12 14 16 18 20 22 24
SHIP SPEED IN KNOTS
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000
HORSEPOWER

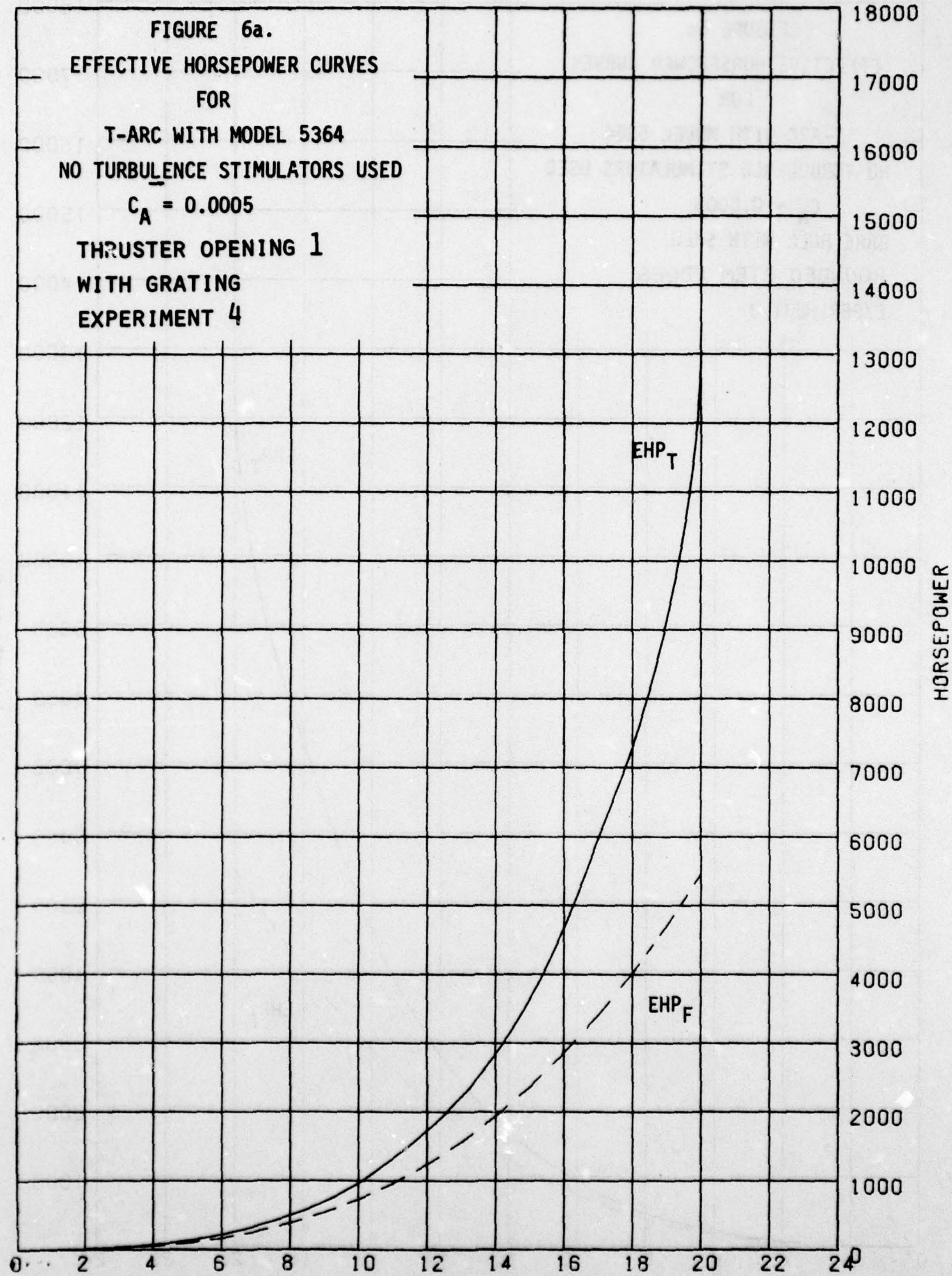


FIGURE 6a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENING 1
WITH GRATING
EXPERIMENT 4
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
HORSEPOWER
0
2
4
6
8
10
12
14
16
18
20
22
24
SHIP SPEED IN KNOTS

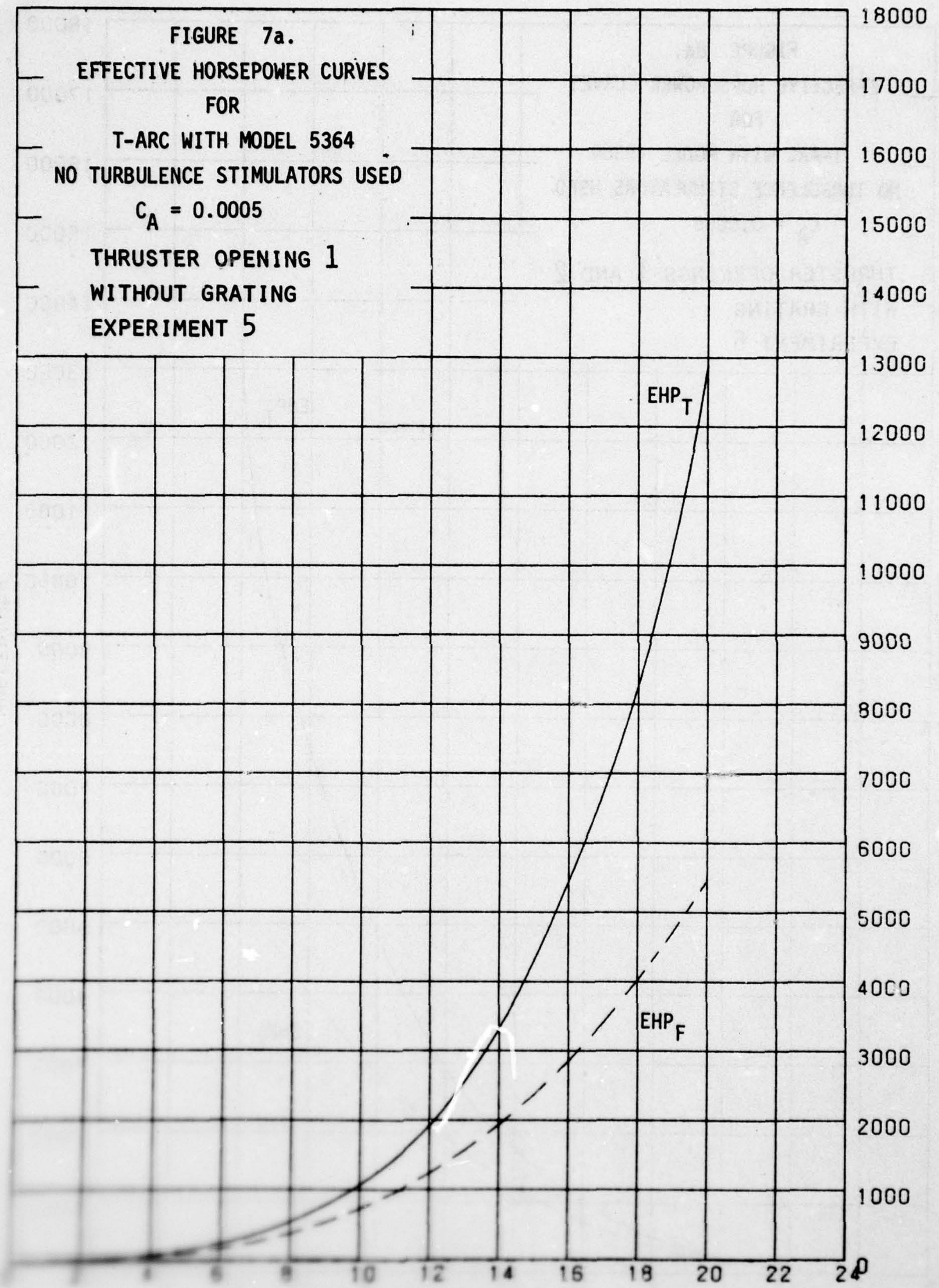


FIGURE 7a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENING 1
WITHOUT GRATING
EXPERIMENT 5
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
HORSEPOWER
10
12
14
16
18
20
22
24
SHIP SPEED IN KNOTS

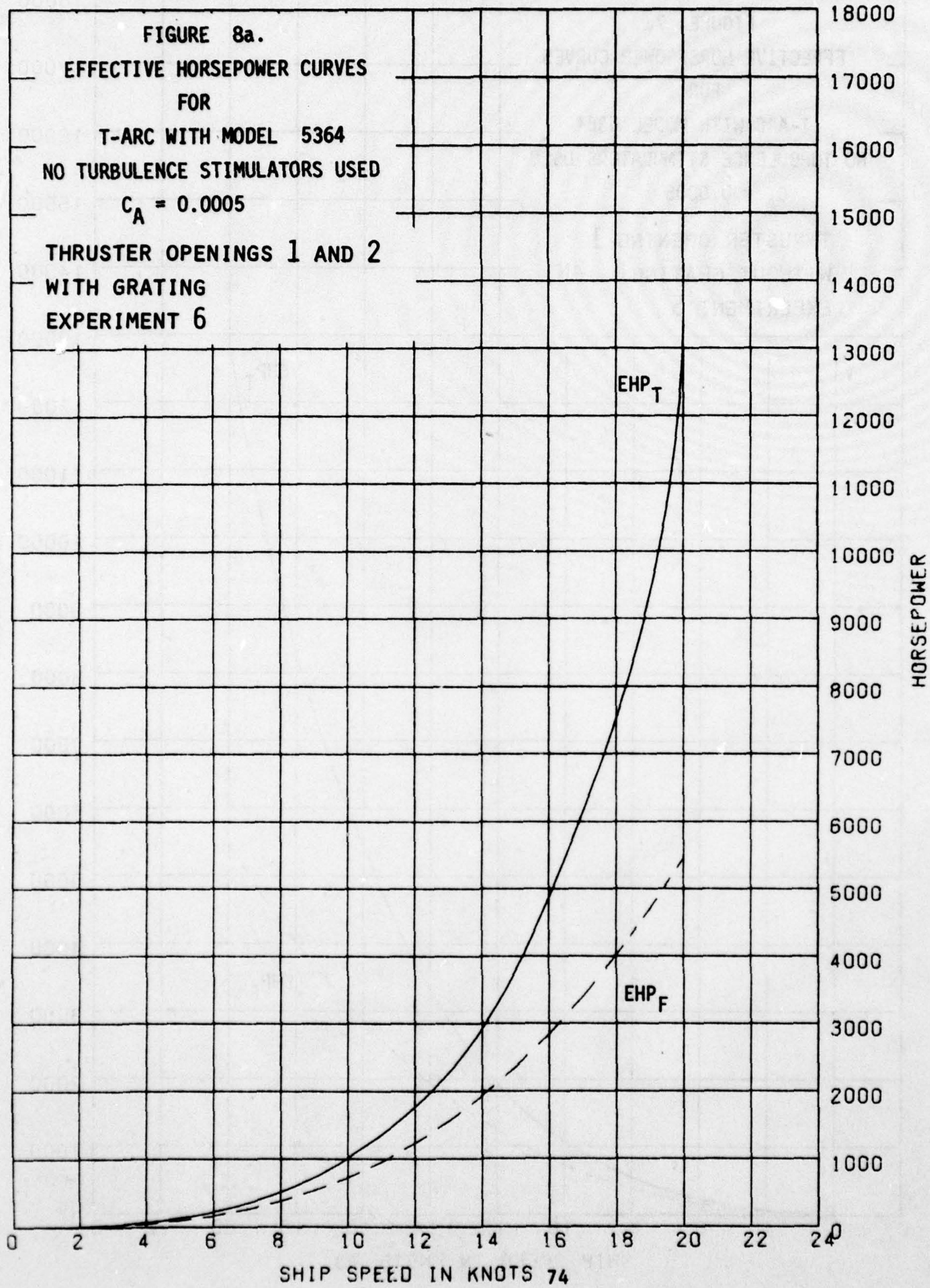


FIGURE 8a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
$C_A = 0.0005$
THRUSTER OPENINGS 1 AND 2
WITH GRATING
EXPERIMENT 6

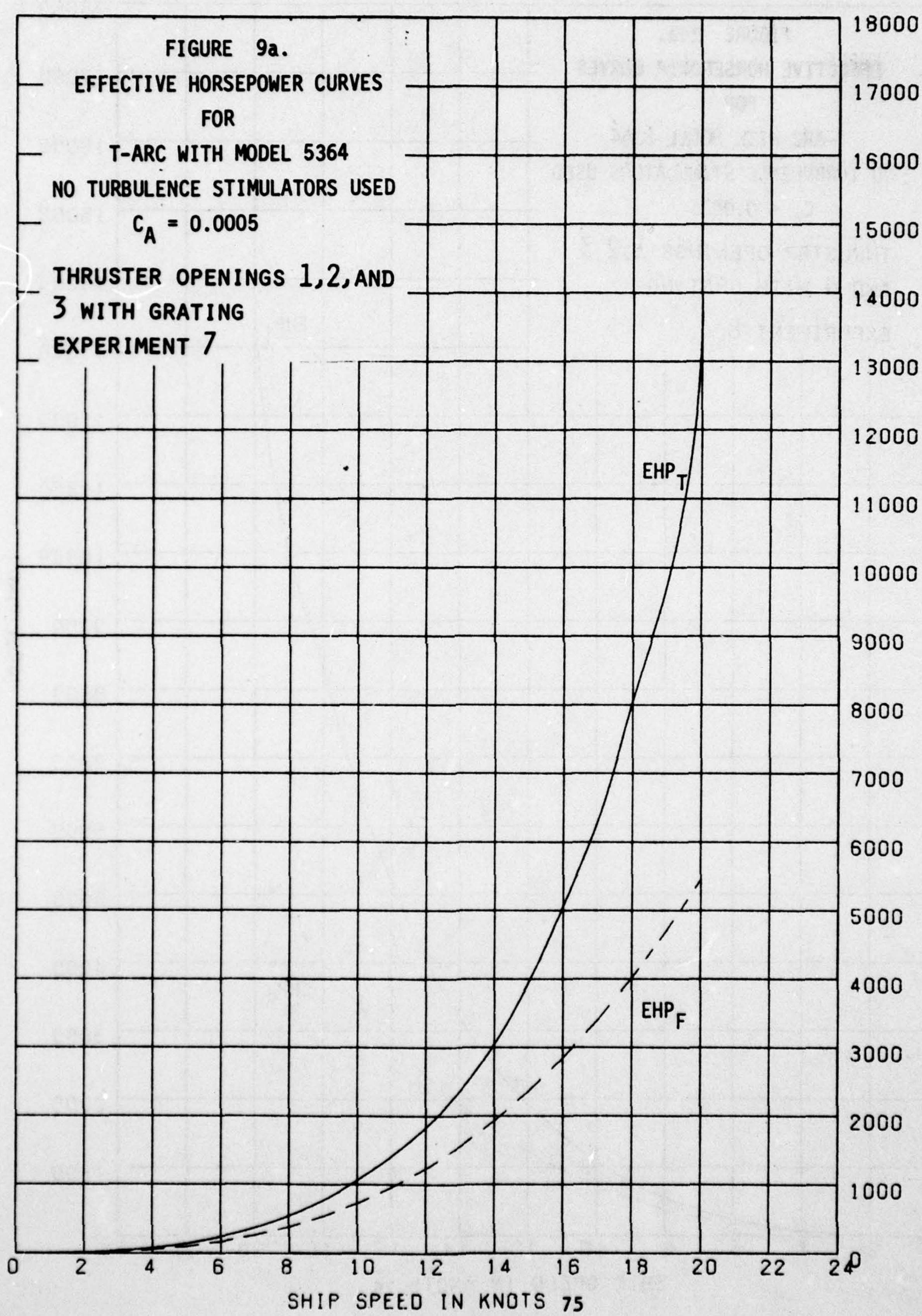


FIGURE 9a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
$C_A = 0.0005$
THRUSTER OPENINGS 1,2,AND
3 WITH GRATING
EXPERIMENT 7
EHP_T
EHP_F
HORSEPOWER
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
0 2 4 6 8 10 12 14 16 18 20 22 24
SHIP SPEED IN KNOTS

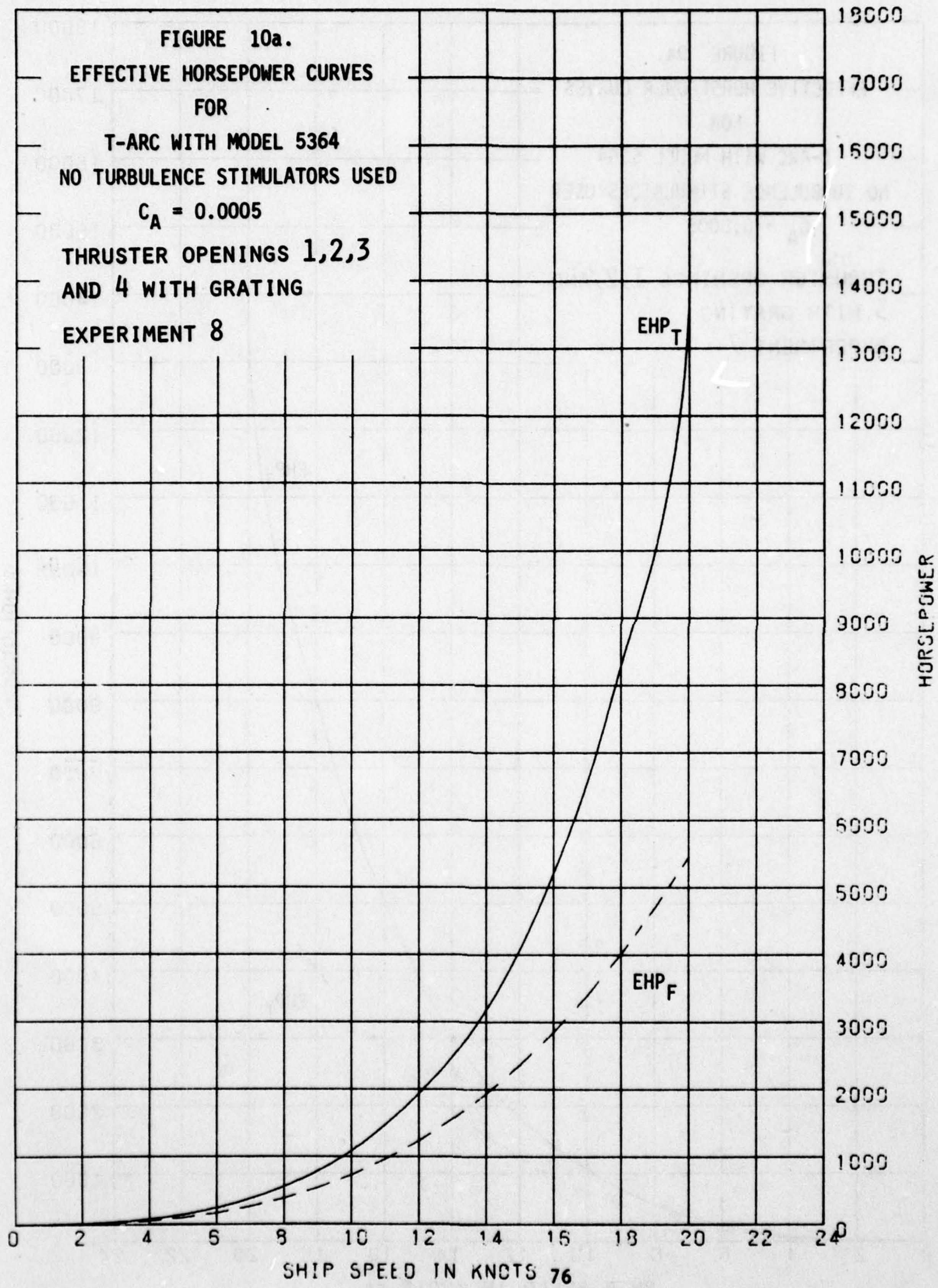


FIGURE 10a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
$C_A = 0.0005$
THRUSTER OPENINGS 1,2,3
AND 4 WITH GRATING
EXPERIMENT 8
EHP_T
EHP_F
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
HORSEPOWER
0
2
4
6
8
10
12
14
16
18
20
22
24
SHIP SPEED IN KNOTS

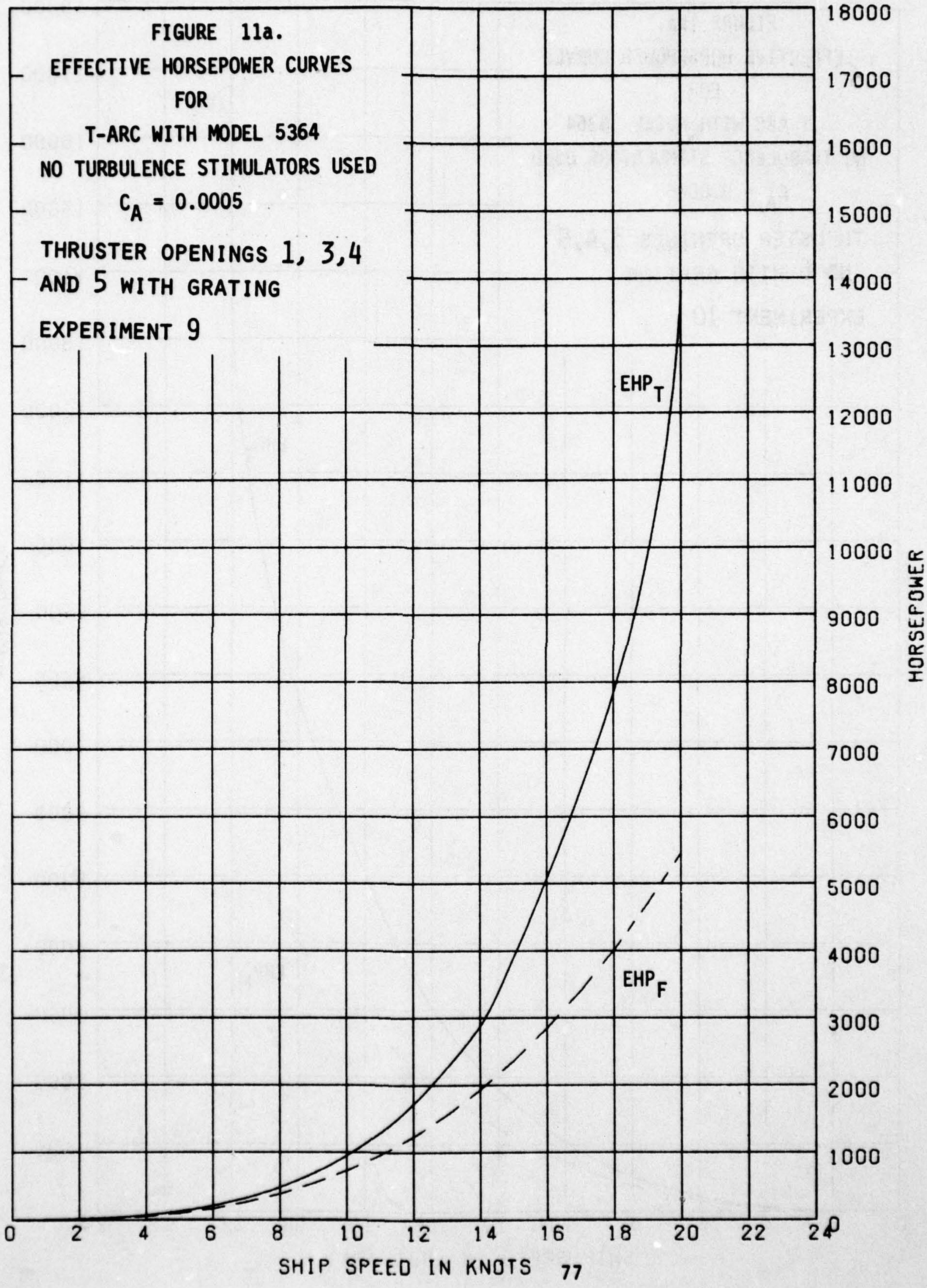


FIGURE 11a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENINGS 1, 3,4
AND 5 WITH GRATING
EXPERIMENT 9
EHP_T
EHP_F
HORSEPOWER
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
16
18
20
22
24
SHIP SPEED IN KNOTS

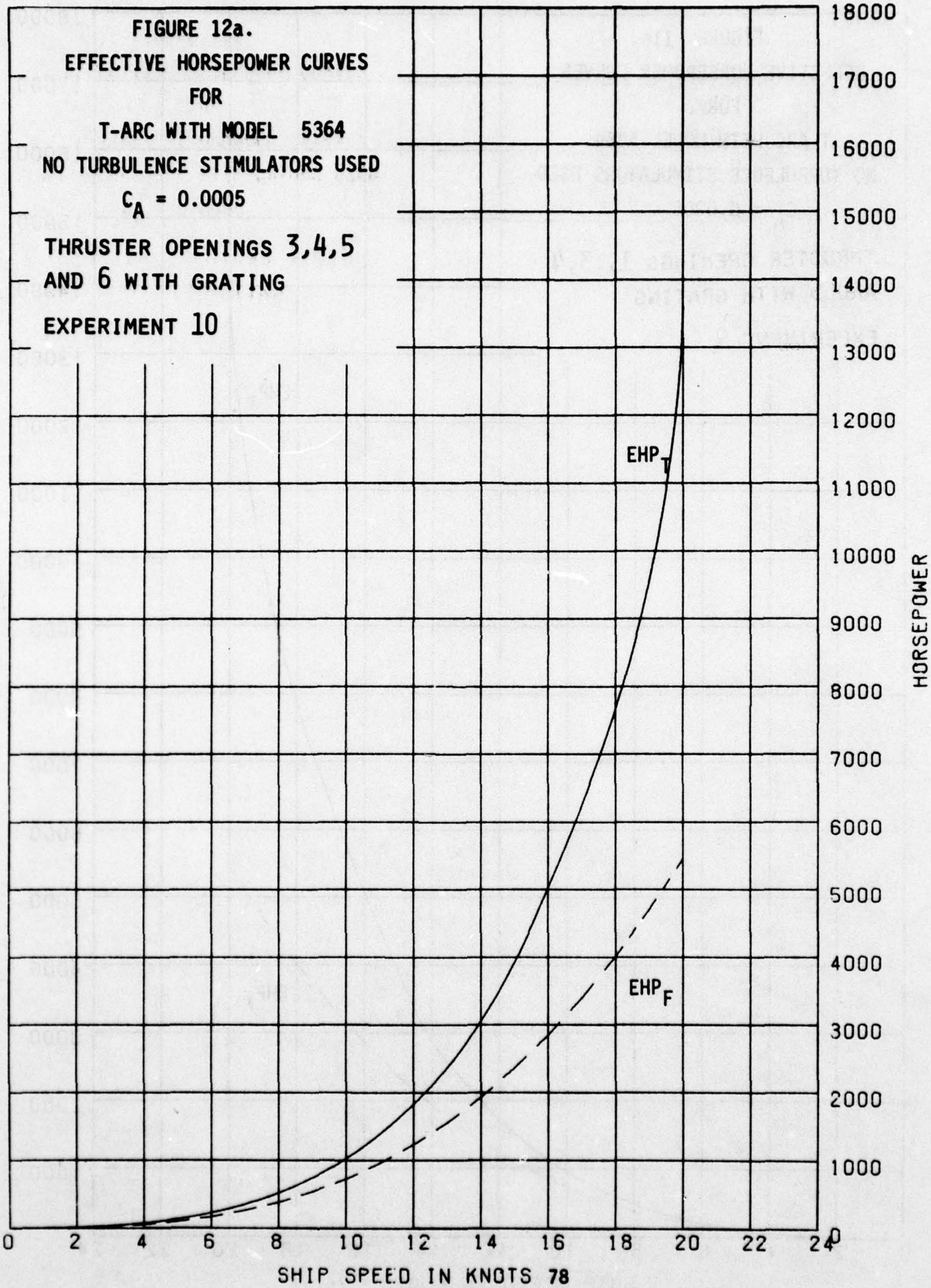


FIGURE 12a.
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC WITH MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
THRUSTER OPENINGS 3,4,5
AND 6 WITH GRATING
EXPERIMENT 10
EHP_T
EHP_F
HORSEPOWER
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 2 4 6 8 10 12 14 16 18 20 22 24
SHIP SPEED IN KNOTS

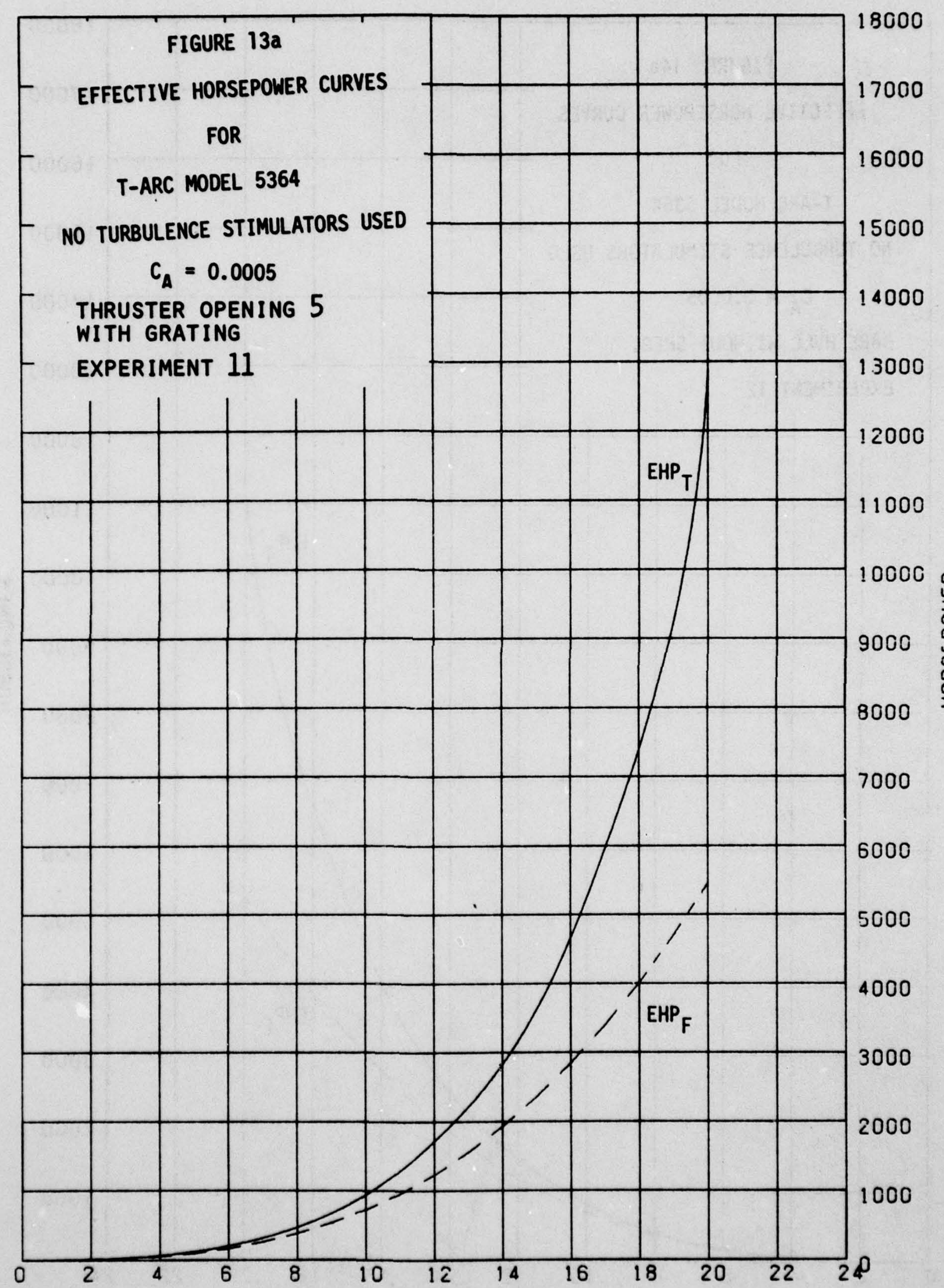


FIGURE 13a
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC MODEL 5364
NO TURBULENCE STIMULATORS USED
$C_A = 0.0005$
THRUSTER OPENING 5
WITH GRATING
EXPERIMENT 11
EHP_T
EHP_F
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
HORSEPOWER
0
2
4
6
8
10
12
14
16
18
20
22
24
SHIP SPEED IN KNOTS

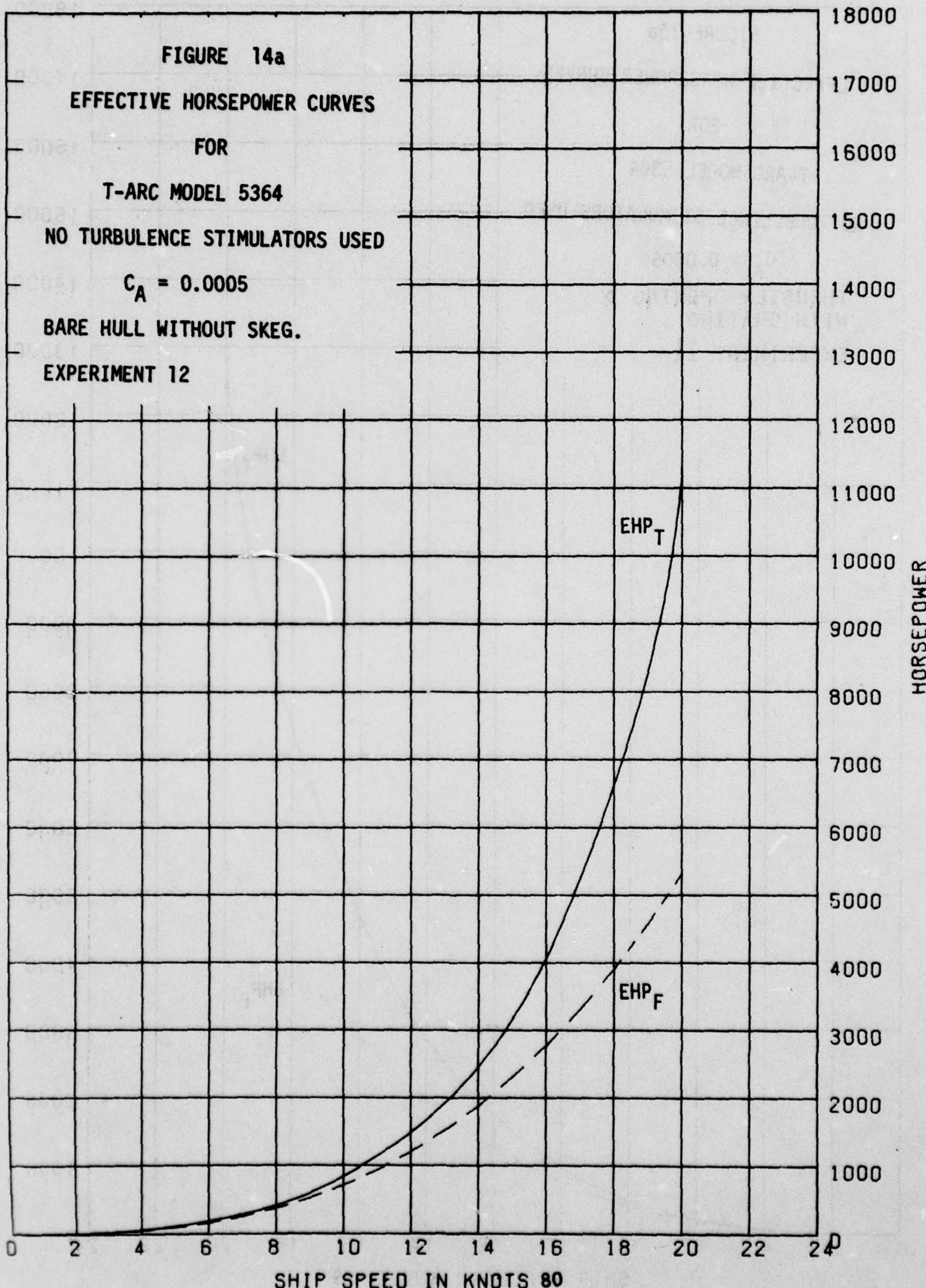


FIGURE 14a
EFFECTIVE HORSEPOWER CURVES
FOR
T-ARC MODEL 5364
NO TURBULENCE STIMULATORS USED
C_A = 0.0005
BARE HULL WITHOUT SKEG.
EXPERIMENT 12
EHP_T
EHP_F
HORSEPOWER
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
16
18
20
22
24
SHIP SPEED IN KNOTS

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